Feasibility Study of

The Methanol Value Chain

November 2022

Feasibility Study of The Methanol Value Chain	
document number:	FS-MVC-01
Edit number:	First Edition
Publication date:	November 2022
Consultant:	SAT Consulting Engineers
Project Manager:	Mahsa Mashayekhi

Table of Contents

1- Introduction 1

2- Market Study 3

2-1- Methanol 3

2-1-1- Product Introduction 3

2-1-2- Market 3

2-2- Low Density Polyethylene (LDPE) 6

2-2-1- Product Introduction 6

2-2-2- Market 6

2-3- Acetic acid 10

2-3-1- Product Introduction 10

2-3-1- Market 10

2-4- Vinyl acetate monomer (VAM) 14

2-4-1- Product Introduction 14

2-4-1- Market 14

2-5- Polyvinyl Acetate 17

2-5-1- Product Introduction 17

2-5-2- Market 17

2-6- Methylamine 21

2-6-1- Product Introduction 21

2-6-2- Market 21

2-7- Polyacetal 25

2-7-1- Product Introduction 25

2-7-2- Market 25

2-8- Formaldehyde 28

2-8-1- Product Introduction 28

2-8-2- Market 28

2-9- Urea-Formaldehyde 32

2-9-1- Product Introduction 32

2-9-2- Market 32

2-10- Melamine-Formaldehyde 36

2-10-1- Product Introduction 36
2-10-2- Market 36
2-11- Phenol-Formaldehyde 41
2-11-1- Product Introduction 41
2-11-2- Market 41
3- Technical Assessment 45
3-1- LDPE 45
3-2- Synthesis gas production Section (HYCO) 50
3-3- Acetic Acid 52
3-4- Vinyl acetate monomer 57
3-5- Polyvinyl alcohol (PVOH) 62
3-6- Methylamines 66
3-7- polyacetal (POM) 68
3-8- Formaldehyde 72
3-8-1- SILVER CATALYST PROCESS Complete Conversion without Methanol Recycle 72
3-9- UREA-FORMALDEHYDE RESINS 75
3-9-1- Introduction 75
3-9-2- Process Description 75
3-10- MELAMINE-FORMALDEHYDE RESINS 78
3-10-1- Introduction 78
3-10-2- Process Description 79
3-11- PHENOL-FORMALDEHYDE (PF) RESINS 83
3-11-1- Introduction 83
3-11-2- Process Description 83
 Novolac Production 84
4- Financial Report Summary 87
4-1- Construction phasing 93

1- Introduction

The purpose of the Feasibility Study and Return on Investment Analysis is to evaluate the supply and demand factors affecting the market for an added value by converting the methanol into products which has the economic viability and added values.

This study has been conducted to prevent the sale of methanol in raw form and convert it into products with higher added value, the production plan of downstream methanol products has been investigated.

The intermediate and final products which has been targeted are as followings:

- LDPE
- Acetic acid
- Vinyl acetate monomer
- Polyvinyl acetate
- Methylamine
- Polyacetal
- Formaldehyde
- Urea-Formaldehyde
- Melamine-Formaldehyde
- Phenol-Formaldehyd

At first, the brief study of feed and products markets is conducted, then according the technical review of the available know-how and technologies are assessed for the construction of downstream production, and in the later stage to have a better financial and investment understanding the feasibility of the proposed plant has been conducted both in financial and economic aspects.

The Block Flow Diagram is shown in the figure below:

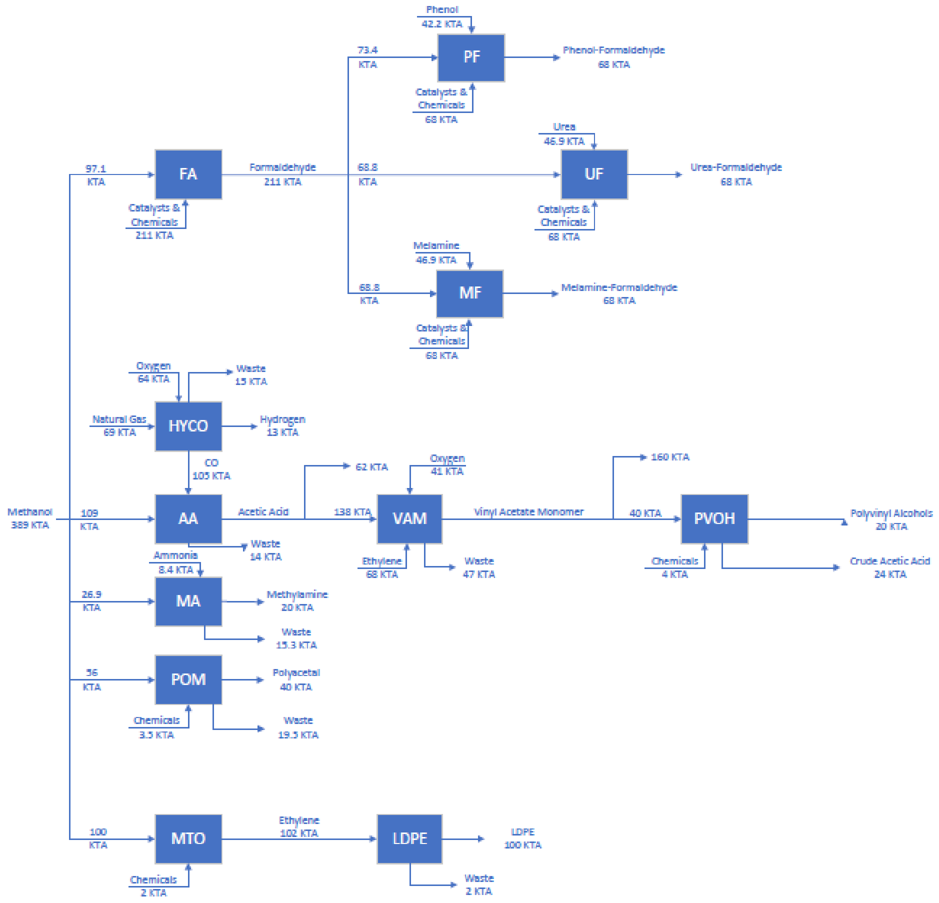


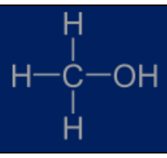
Figure 1- Block Flow Diagram (BFD)

2- Market Study

2-1- Methanol

2-1-1- Product Introduction

Table 1- Table of characteristics of Methanol

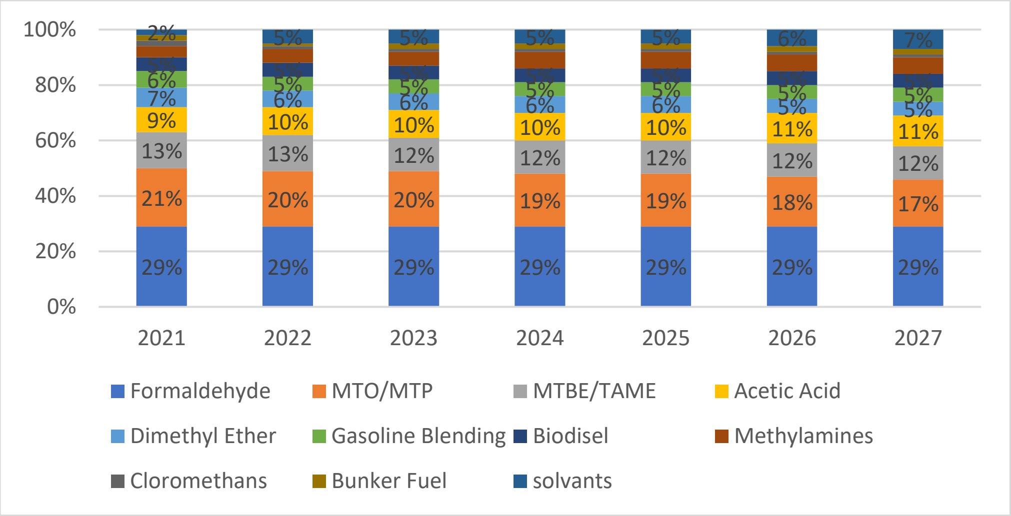


Molecular formula	$C_1H_4O_1$
Molar mass	32.04 g mol^{-1}
Appearance	Colorless liquid
Density	0.7918 g cm^{-3}
Boiling point	65 degrees Celsius (149 degrees Fahrenheit; 338 Kelvin)
log P	-0.69
Vapor pressure	13.02 kPa (at 20 °C)
Acidity (pKa)	15.5
Viscosity	5.9×10^{-4} Pa s (at 20 °C)
Dipole moment	1.69 D

2-1-2- Market

Methanol is used in industries as an intermediate feed for the production of other chemicals that have a wide range of applications. Methanol demand by derivatives in 2021 and the forecast of their demand ratio of methanol to 2027 are shown in the graphs below.

Figure 2- Methanol Demand by Derivatives



Source: IHS Markit

Product Name: Methanol	
Global Market	
Production Capacity: 130million tons per year	**Total Consumption:** 83 million tons per year
Major Producing Countries and Regions: North-East Asia, Africa, Middle East	**Major Consuming Countries and Regions:** North-East Asia, North America
World trade: 30 million tons per year	
Major Exporters: Saudi Arabia, USA	**Major Importers:** China
Forecast (2027)	
Production Capacity:149 million tons per year	**Total Consumption:** 101 million tons per year
Major Producing Countries and Regions: North-East Asia, Africa, Middle East	**Major Consuming Countries and Regions:** North-East Asia, North America
World trade: 36 million tons per year	
Major Exporters: Middle East, USA	**Major Importers:** China

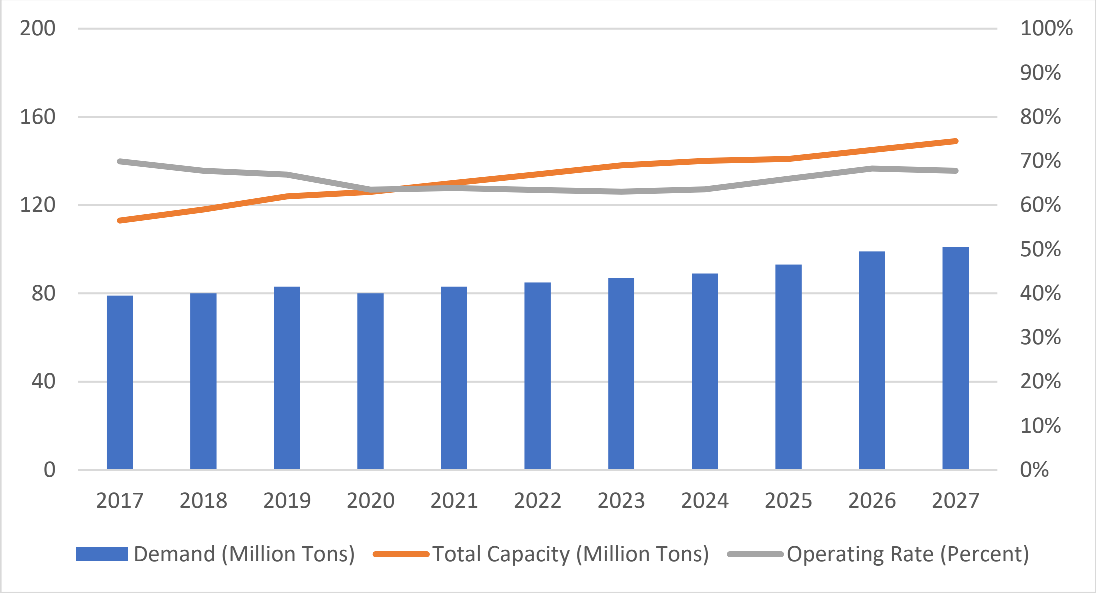
Insight:

After the global recession of 2008, the methanol market began to grow slowly and until 2010, it was accompanied by an increase in demand but with a slow trend. In the first quarter of 2014, the price of chemical products, especially methanol, increased significantly, and after the price reached the peak, a sudden drop off in price occurred. Since 2014, the global price of methanol has decreased several times. In 2017, China announced its intention to replace methanol with ethanol by 2020, and this greatly affected the methanol market in 2017. Of course, despite this claim, methanol demand has grown by 5.2% between 2014 and 2019, and one of the main reasons for this demand growth has been the increase in MTO demand in China.

Considering 2020 as the base year for this study, the plans made in the methanol market predict a growth of 2.8% for the demand of this product in the next ten years. Methanol demand has grown significantly in recent years, and this growth is more than any other factor due to the increase in MTO demand, but forecasts show that MTO demand will grow at a rate of 1.4% between 2020 and 2030, because with the low price of crude oil, MTO sector face a higher cost than low-cost Sectors such as olefins, cracked naphtha and PDH Sectors, and therefore these Sectors are expected to operate at lower capacities between 2022 and 2026.

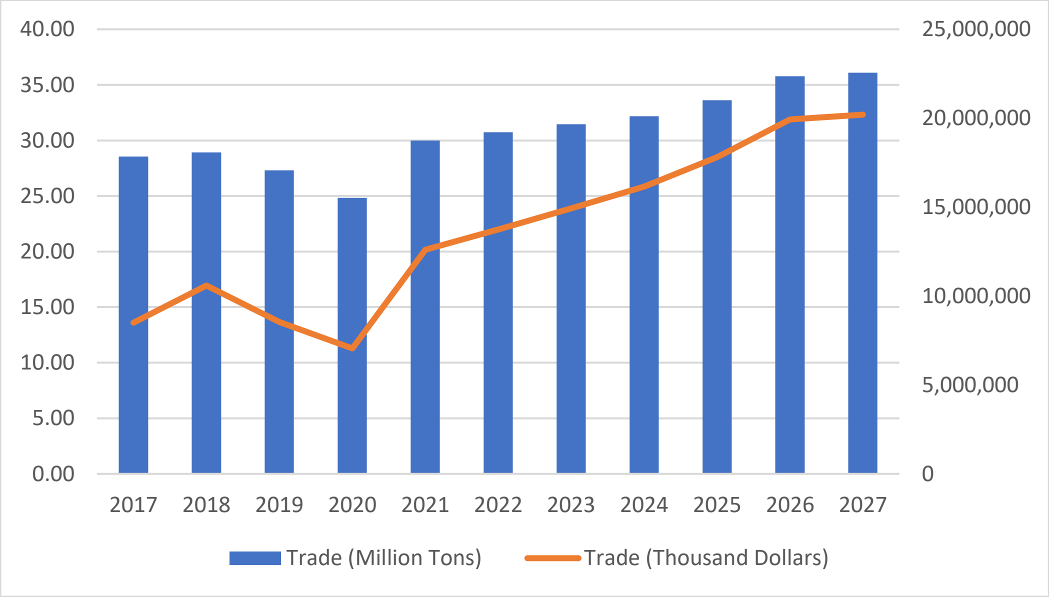
According to the installed capacity in the world, the actual amount of production and the number of projects in progress in the world, as well as the change of policies in the manufacture of gasoline cars and the reduction of fossil fuel consumption, the price of methanol in the world market in general, as well as in China in particular, will be in a way that the implementation of downstream methanol projects will be profitable.

Figure 3- Methanol Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 4- Methanol Word Trade Trend and Forecast

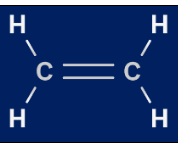


Source: ITC

2-2- Low Density Polyethylene (LDPE)

2-2-1- **Product Introduction**

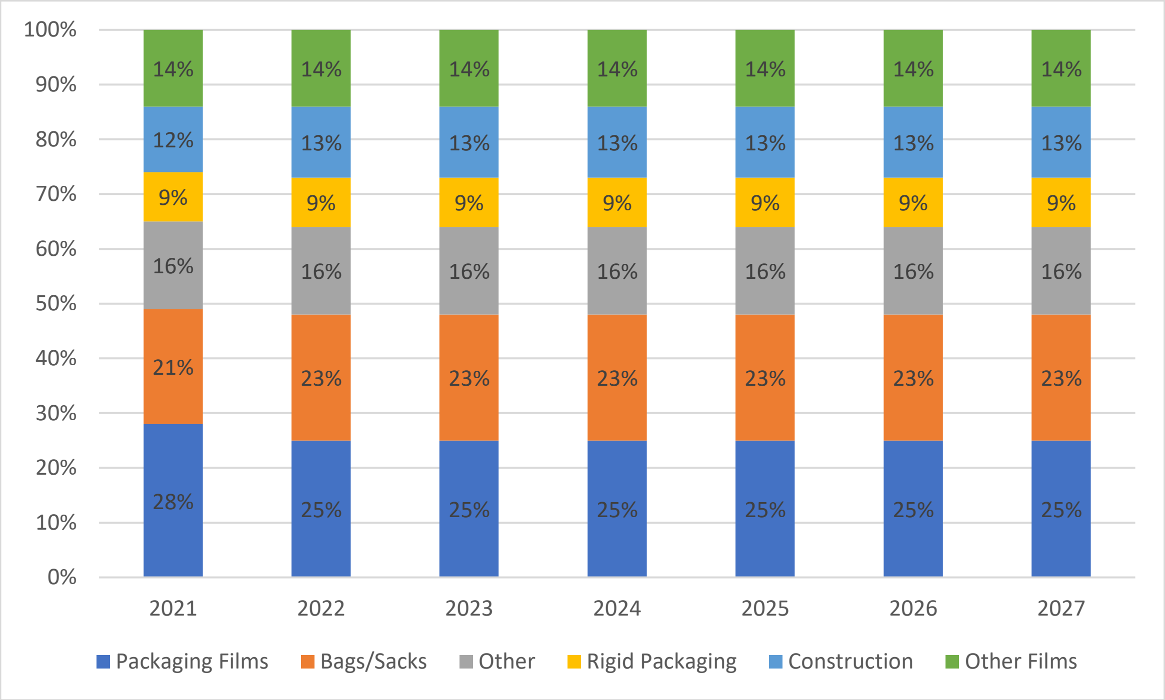
Table 2- Table of characteristics of LDPE

	
Density	Low density 0.91-0.94 g/cm3
Flexibility	Low crystallinity (50-60%), and therefore more flexible
Heat resistance	Drastic decrease in density when subjected to temperatures beyond 20°C
Melting point	~115°C
Chemical resistance	Resistant to most alcohols, acids, and alkalis; low resistance to oxidising agents and selected hydrocarbons
Strength	Relatively increased impact strength in cold conditions
Transparency	High, due to amorphous condition
Maximum allowable stress at 20°C	6–17 MPa

2-2-2- **Market**

Polyethylene is one of the top-selling standard plastics, its consumption continues to increase despite all environmental discussions on the ground. It is classified into different grades according to its density and the branching of its polymer chains: LDPE, LLDPE, and HDPE. low-density polyethylene (LDPE) that is the oldest polyethylene grade, which has been produced since 1939. LDPE is soft, tough, and flexible. LDPE is therefore used for numerous consumer goods, such as screw caps and lids.

Figure 5- LDPE Demand by Derivatives



Source: IHS Markit

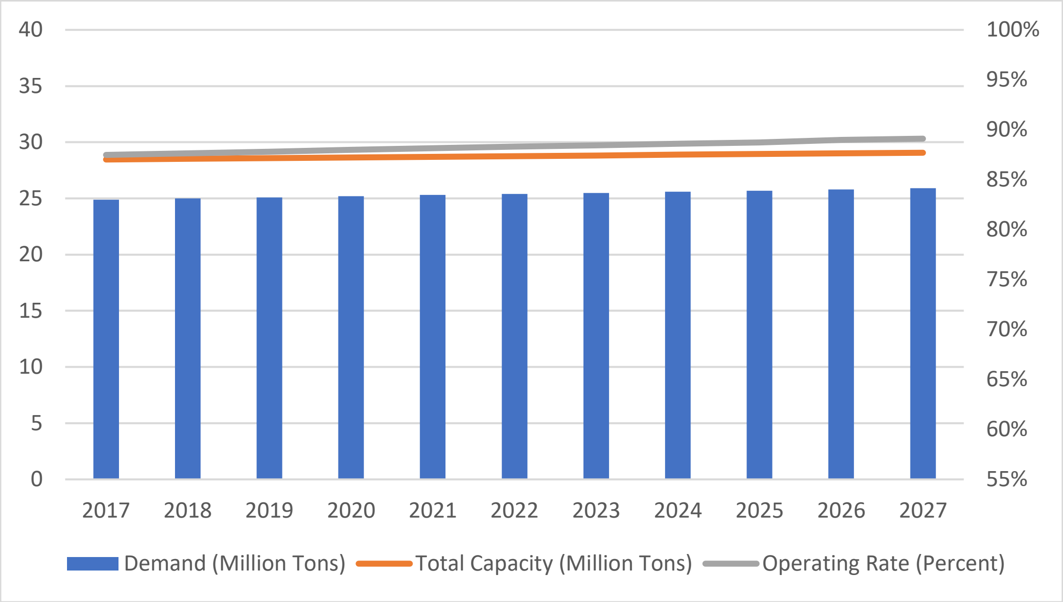
Product Name: LDPE	
Global Market	
Production capacity: 28.7 milliontons per year	**Total Consumption:** 25.3 million tons per year
Major Producing Countries and Regions: USA, Russia, China	**Major Consuming Countries and Regions:** North-East Asia, West Europe
World trade: 12 million tons per year	
Major Exporters: USA, Middle East	**Major** Importers**:** China
Forecast (2027)	
Production capacity: 25.9 million tons per year	**Total Consumption:** 29.06 million tons per year
Major Producing Countries and Regions: North-East Asia, Africa, Middle East	**Major Consuming Countries and Regions:** North-East Asia, North America
World trade: 12.85 million tons per year	
Major Exporters: Middle East, USA	**Major** Importers: China**,** India

Insight:

Sales of low-density polyethylene increased at 4.4% CAGR, between 2014 and 2021 owing to significant demand from the application segments. The covid-19 pandemic reduce demand for low density polyethylene, also impacted the sales in 2020. Growing use of LDPE for manufacturing film & sheets and extruded coatings for packaging purposes are driving the demand for the market all over the globe.

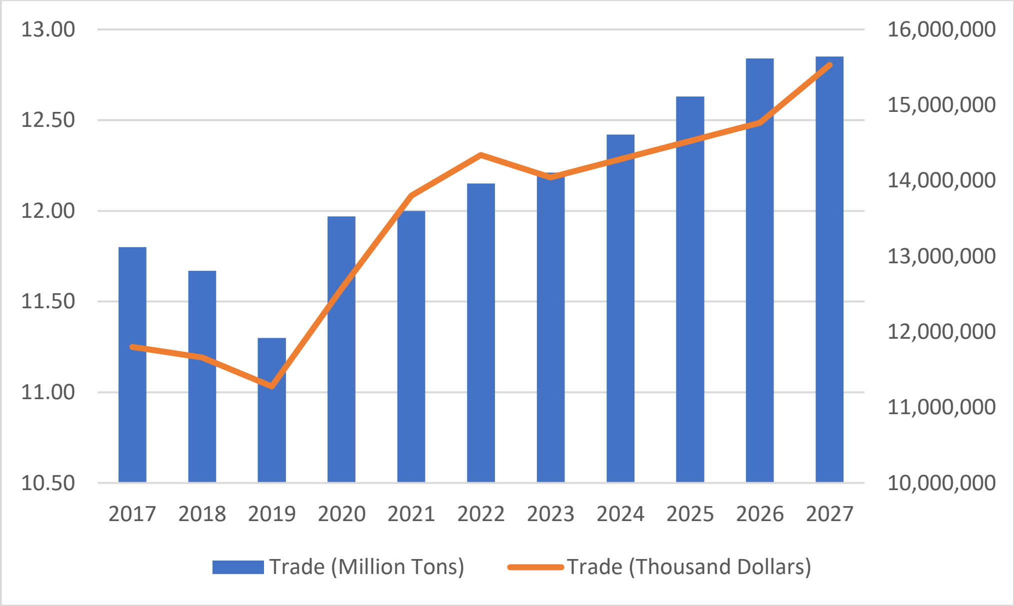
Increasing applications of low-density polyethylene in various end use industries is expected to propel the sales over the forecast period. Films & sheets and coatings are the key applications which are pushing the demand for low density polyethylene.

Figure 6- LDPE Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 7- LDPE Wold Trade Trend and Forecast

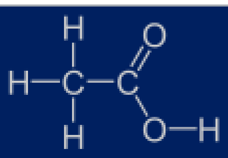


Source: IHS Markit

2-3- Acetic acid

2-3-1- **Product Introduction**

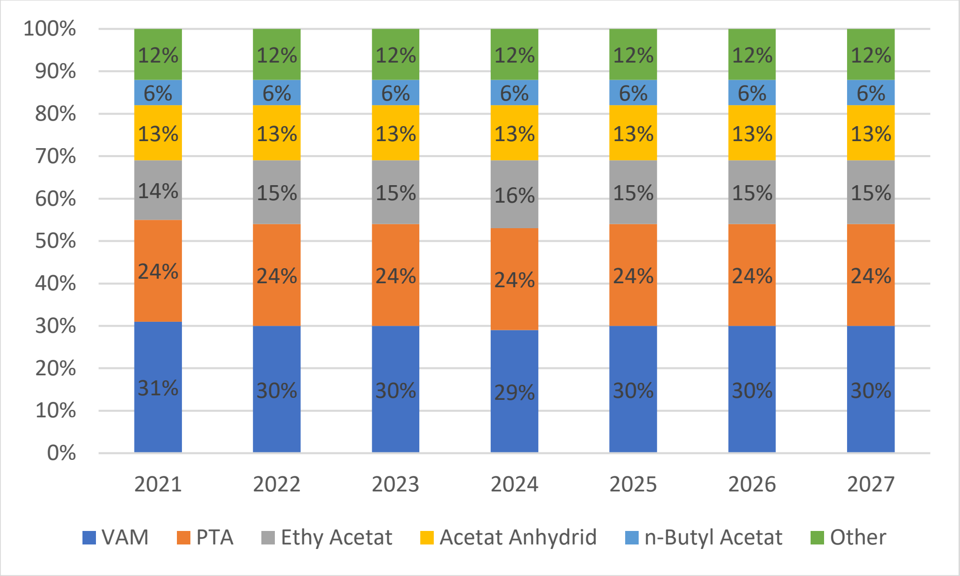
Table 3- Table of characteristics of Acetic Acid

	
Chemical formula	CH_3COOH
Molar mass	60.052 g·mol^{-1}
Appearance	Colourless liquid
Odor	Heavily vinegar-like
Density	1.049 g/cm^3 (liquid); 1.27 g/cm^3 (solid)
Melting point	16 to 17 °C; 61 to 62 °F; 289 to 290 K
Boiling point	118 to 119 °C; 244 to 246 °F; 391 to 392 K
Solubility in water	Miscible
log *P*	-0.28
Vapor pressure	11.6 mmHg (20 °C)
Acidity (pK_a)	4.756
Conjugate base	Acetate
Magnetic susceptibility (χ)	-31.54·10^{-6} cm^3/mol
Refractive index (n_D)	1.371 (V_D = 18.19)
Viscosity	1.22 mPa s
Dipole moment	1.74 D

2-3-1- **Market**

Acetic acid is one of the derivatives of methanol, which is used to produce vinyl acetate, ethanol, acetic anhydride, acetate esters, terephthalic acid and monochloroacetic acid. Acetic acid and its derivatives are required by various industries such as pharmaceuticals, solvent industry, adhesive industry, film making, textile, electronics, drilling, leather industry, printing industry, paint and resin industry and also a major use in food industry.

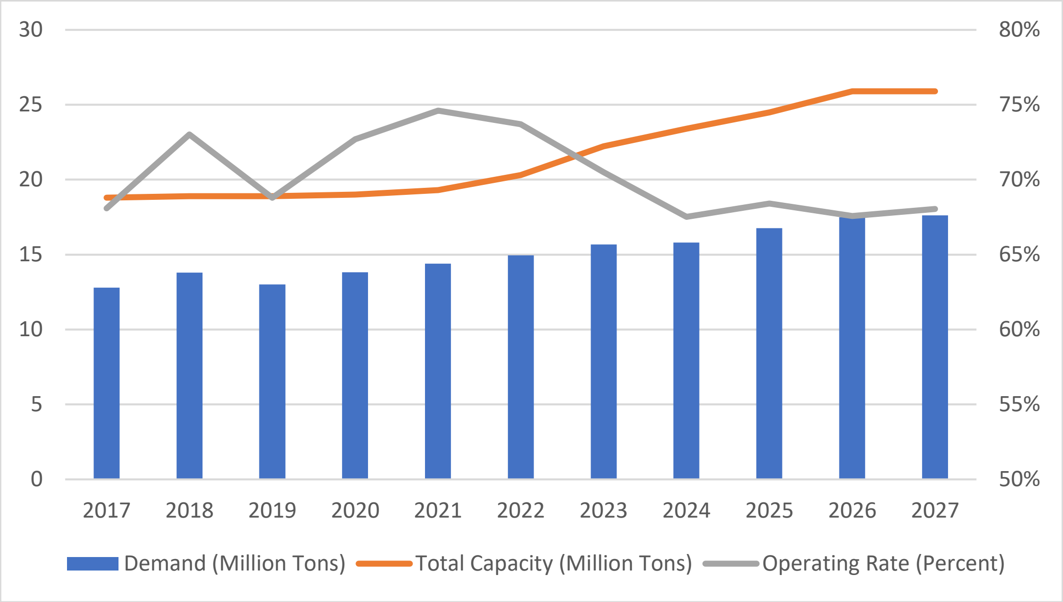
Figure 8- Acetic Acid Demand by Derivatives



Source: IHS Markit

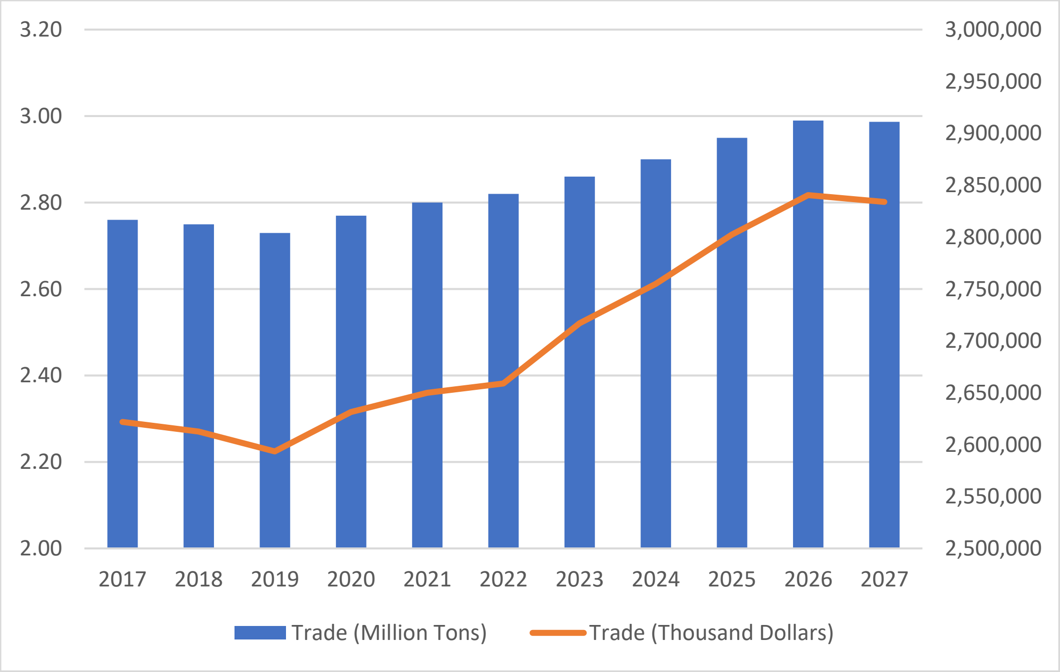
Product Name: Acetic Acid	
Global Market	
Production capacity: 19.3 million tons per year	**Total Consumption:** 14.4 million tons per year
Major Producing Countries and Regions: North-East Asia, North America	**Major Consuming Countries and Regions:** North-East Asia, North America
World trade: 2.8 million tons per year	
Major Exporters: China	**Major** Importers**:** North America
Forecast (2027)	
Production capacity: 25.9 million tons per year	**Total Consumption:** 17.6 million tons per year
Major Producing Countries and Regions: North-East Asia, Africa, Middle East	**Major Consuming Countries and Regions:** North-East Asia, North America
World trade: 2.99 million tons per year	
Major Exporters: China	**Major** Importers**:** North America
insight: The process of rebuilding US industries is happening slowly, and it is expected that the production of acetic acid in China and India will increase, and India will also limit its storage process due to the subsidence of the Corona Virus. Therefore, it is expected that the supply of acetic acid will gradually increase, and on the other hand, the demand will decrease. All these observations, show that we should expect a decrease in the price of acetic acid in the future. The trend of acetic acid price fluctuations also shows that the current price of acetic acid has decreased by more than 20% compared to its price ceiling.	

Figure 9- Acetic Acid Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 10- Acetic Acid World Trade Trend and Forecast

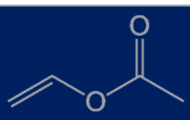


Source: ITC

2-4- Vinyl acetate monomer (VAM)

2-4-1- **Product Introduction**

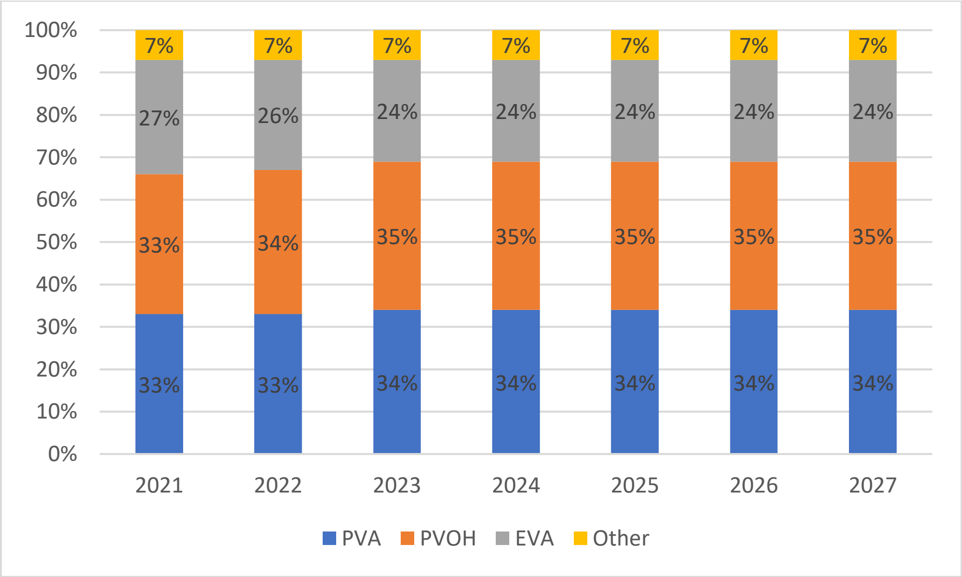
Table 4- Table of characteristics of Vinyl acetate monomer

	
Molecular formula	C4H6O2
Molar mass	86.09 g/mol
Appearance	Colorless liquid
Density	0.934 g/cm3
Melting temperature	-93 °C
Boiling temperature	72.7 °C

2-4-1- **Market**

VAM-based polymers, including copolymers of vinyl chloride, vinyl acetate, polyvinyl acetate (PVA), and polyvinyl alcohol (PVOH), are used in various applications.

Figure 11- VAM Demand by Derivatives



Source: IHS Markit

Product Name: VAM	
Global Market	
Production capacity: 8.47 million tons per year	**Total Consumption:** 6.7 million tons per year
Major Producing Countries and Regions: North-East Asia, North America	**Major Consuming Countries and Regions:** China
World trade: 2.52 million tons per year	
Major Exporters: Singapore, USA	**Major** Importers**:** Belgium, China
Forecast (2027)	
Production capacity: 10.6 million tons per year	**Total Consumption:** 8.52 million tons per year
Major Producing Countries and Regions: North-East Asia, Africa, Middle East	**Major Consuming Countries and Regions:** North-East Asia, North America
World trade: 2.85 million tons per year	
Major Exporters: Singapore, USA	**Major Importers:** Belgium, China, India

Insight:

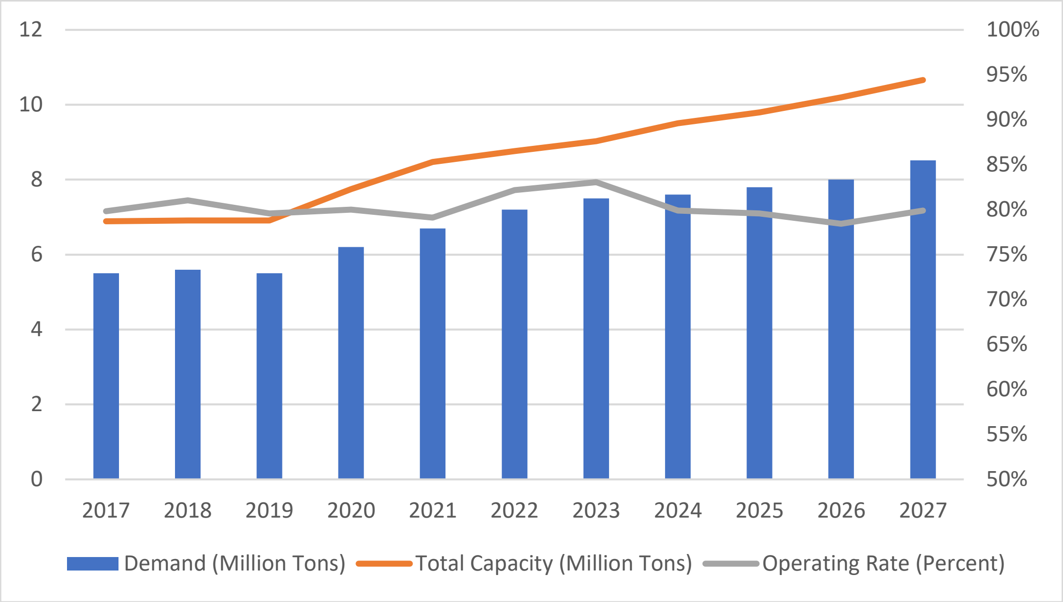
By growing the packaging industries across the globe drives the growth of the Vinyl Acetate Monomer market. Due to convenience and improved product shelf, the demand for the packaged beverages and food products increases which may expect to rise the market growth.

By introducing the latest multiple-layer barrier packaging technology in the packaging industry the demand for the Vinyl Acetate Monomer rises and has a significant effect on demand increase.

By rising the residential and commercial infrastructure activities in both developed and developing regions, the consumption of vinyl acetate monomer is increased in the construction industry.

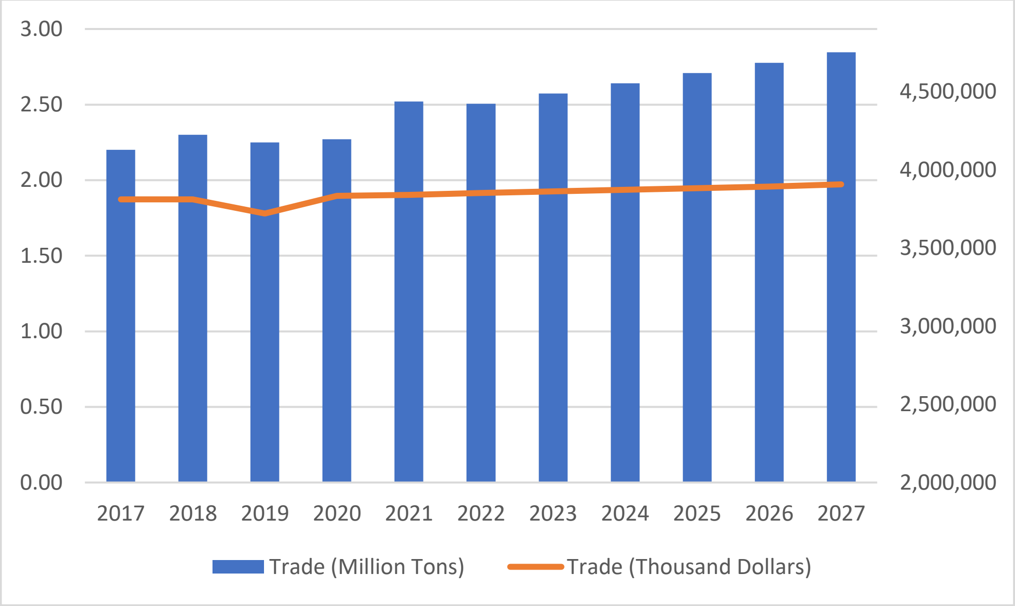
By accelerating the demand for adhesives, paints, and coatings from major industries like construction, automotive, and packaging industry results in propelling the market growth.

Figure 12- Vinyl Acetate Monomer Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 13- Vinyl Acetate Monomer World Trade trend and forecast

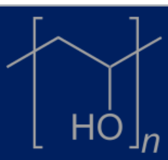


Source: ITC

2-5- Polyvinyl Acetate

2-5-1- **Product Introduction**

Table 5- Table of characteristics of Polyvinyl Acetate (Polyvinyl alcohol)

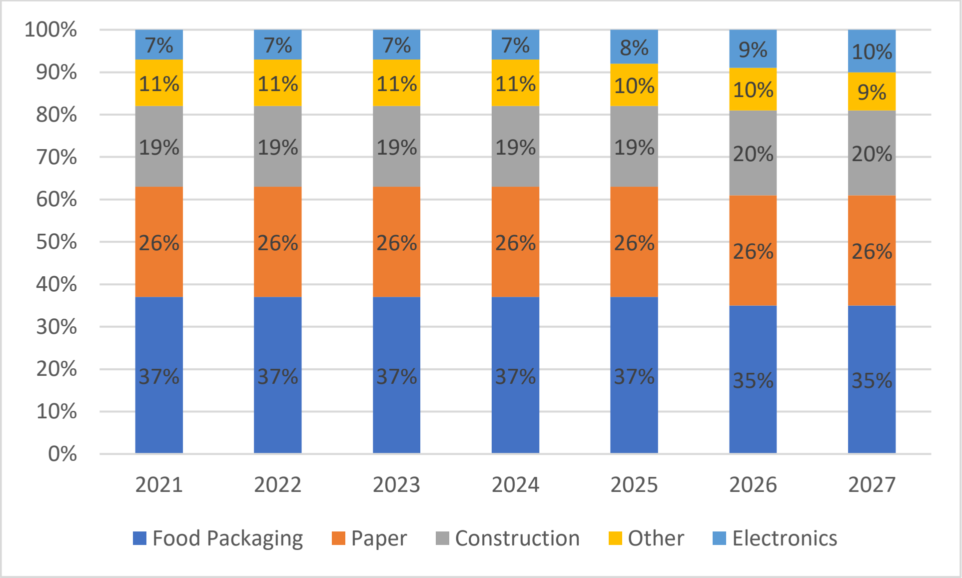


Product Name	Polyvinyl Acetate
Abbreviation of polyvinyl alcohol	PVOH, PVA, PVAl
Chemical formula	C_2H_4O
Melting point	200 °C
Boiling point	228 °C
Density	1.19 g/cm^3

2-5-2- **Market**

PVA, a synthetic water-soluble polymer, has been the key ingredient in formulation processes in various end-use industries including food packaging, construction, electronics, coatings, printing, textile, cosmetics, and paper. Demand for the same is mainly driven by the food packaging industry, as it is a material with excellent water solubility and biodegradable properties.

Figure 14- Polyvinyl Alcohol Demand by Derivatives



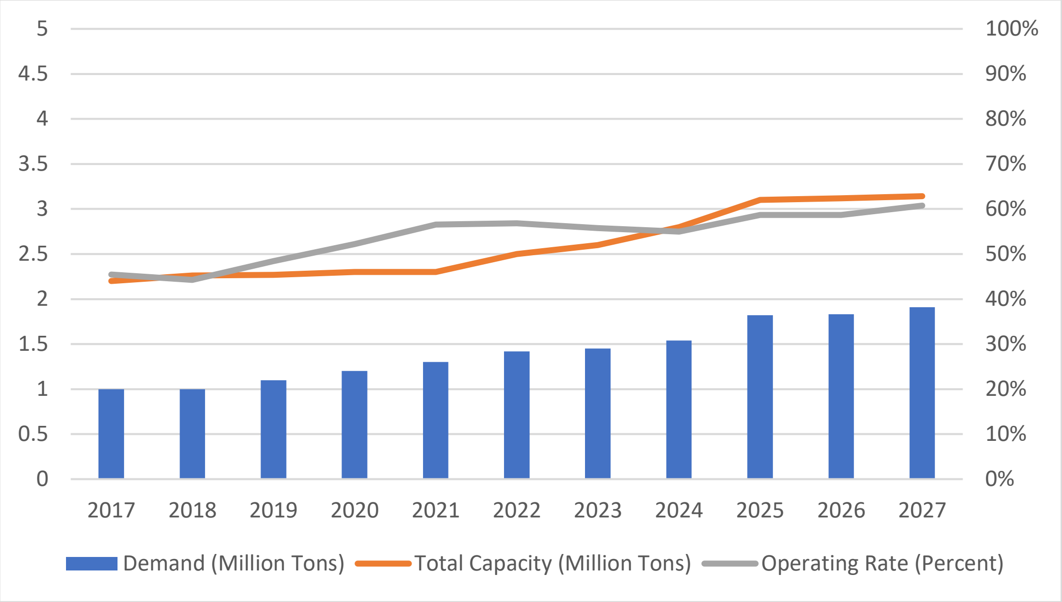
Product Name: Polyvinyl Acetate	
Global Market	
Production capacity: 2.3 million tons per year	**Total Consumption:** 1.3 million tons per year
Major Producing Countries and Regions: North-East Asia	**Major Consuming Countries and Regions:** China
World trade; 503,000 tons per year	
Major Exporters: China	**Major** Importers**:** Belgium, Germany, Netherlands
Forecast	
Production capacity: 3.14 million tons per year	**Total Consumption:** 1.9 million tons per year
Major Producing Countries and Regions: North-East Asia	**Major Consuming Countries and Regions:** China
World trade: 593,000 tons per year	
Major Exporters: China	**Major** Importers**:** Belgium

insight:

The global polyvinyl alcohol market was valued at USD 791.7 million in 2021 and is expected to grow at a CAGR of 6.3% during the forecast period.
The increasing demand in end-use industries, including paper, food packaging, construction, electronics, and others segments including printing, textiles, and coatings, is expected to drive the polyvinyl alcohol market over the forecast period.
Polyvinyl alcohol is primarily fueled by packaging sector demand since it is a substance with excellent oxygen resistance, absorption in water, and biodegradability. Furthermore, the expanding potential in the electronic industry for producing devices such as transistors that require high dielectric properties is expected to create lucrative support for the polyvinyl alcohol market growth.
The sustainable packaging solution has gained importance on account of the safety, performance, and convenience of the packaged products.
Polyvinyl alcohol film is a widely used polymer and has contributed significantly to the growth of the packaging industry. However, the volatile raw materials prices required for the production of polyvinyl alcohol are expected to challenge the polyvinyl alcohol market growth.
Food packaging segment is expected to dominate the industry over the forecast period. The growing demand for non-toxic and biodegradable packaging solutions in the food & beverage sector, advantages such as moisture resistance, and increasing trends such as out-of-home consumption are some factors anticipated to boost the segment growth.

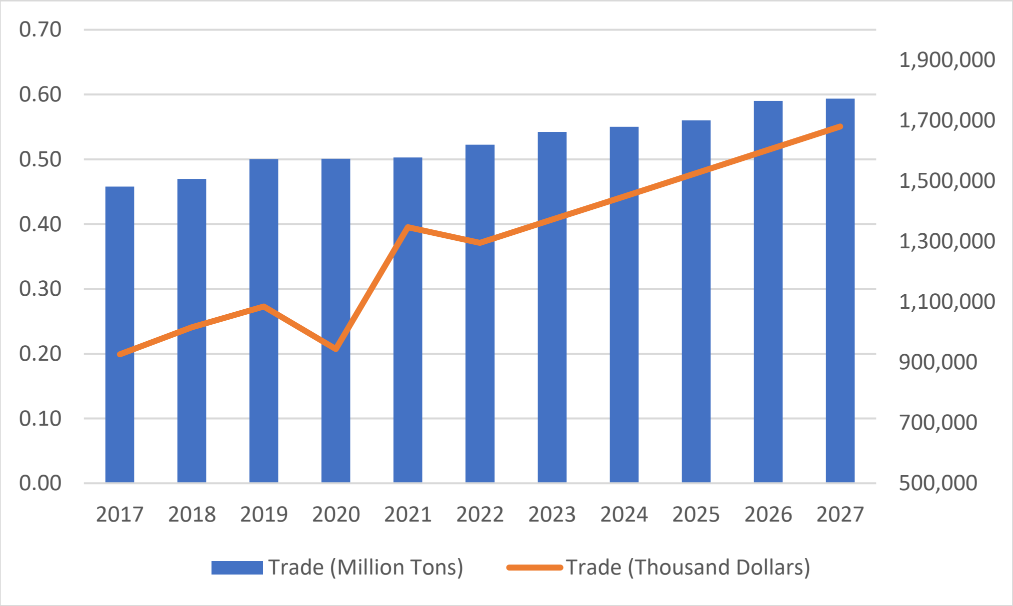
Construction segment is expected to grow at a significant pace over the forecast period due to polyvinyl alcohol's numerous properties, including static percolation of cement slurries, adsorption capacity, along with superior solubility in water and particle density.

Figure 15- Poly Vinyl Acetate Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 16- Poly Vinyl acetate World Trade Trend and Forecast

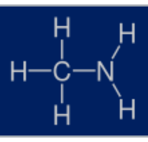


Source: ITC

2-6- Methylamine

2-6-1- **Product Introduction**

Table 6- Table of characteristics of Polyvinyl Acetate

	
molecular formula	CH_3NH_2
Molar mass	31.06 g mol^{-1}
Appearance	Colorless gas
the smell	Fishy ammoniacal
melting point	-93.1 °C
Solubility in water	1.08 kg L^{-1} (at 20 °C)
log P	-0.472
Vapor pressure	186.10 kPa (at 20 °C)
KH	1.4 mmol Pa^{-1} kg^{-1}
Viscosity	230 μPa s (at 0 °C)
Dipole moment	1.31 D

2-6-2- **Market**

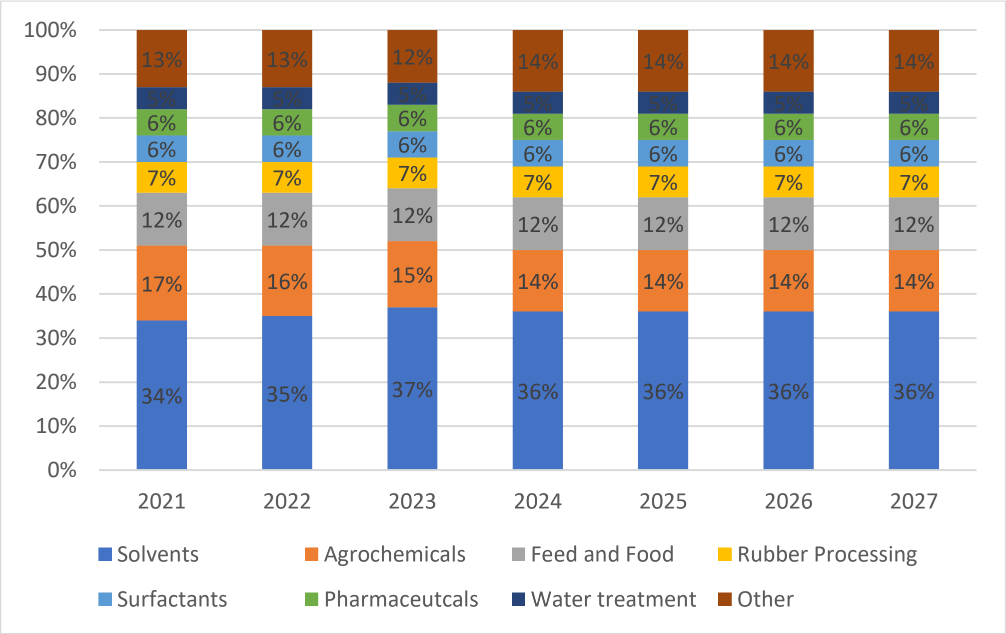
Major applications of methyl amine include pesticides, N-methyl pyrrolidone, alkyl alkanolamines, pharmaceuticals, and others. Methyl amine is used in the manufacturing of pesticides which are majorly used for crop protection. The demand for pesticides has increased significantly over the past few years owing to rapid urbanization & industrial growth along with technological advancements in farming practices. This trend is expected to continue over the forecast period thereby driving market growth across all application segments during the study period. Methyl amine is also utilized as a solvent in various industries including paints & coatings and lubricants among others which comprises products such as grease and oil among other similar formulations that require high-purity methyl amines as an essential ingredient for their production processes.

Major players operating in the global methylamine market are adopting various organic and inorganic growth strategies such as joint ventures, mergers & acquisitions, expansion, collaborations, new product launches, strategic alliances, and research and development to increase their regional presence

and business operations. The market is currently witnessing fierce competition among several leading players. Key players operating in the market include:

- Alkyl Amines Chemicals Limited
- Balaji Amines Ltd.
- Balchem Corporation
- BASF SE
- Celanese Corporation
- Eastman Chemical Company
- Johnson Matthey Plc
- Luxi Chemical Group Co., Ltd.
- MITSUBISHI GAS CHEMICAL COMPANY, INC.
- The Chemours Company

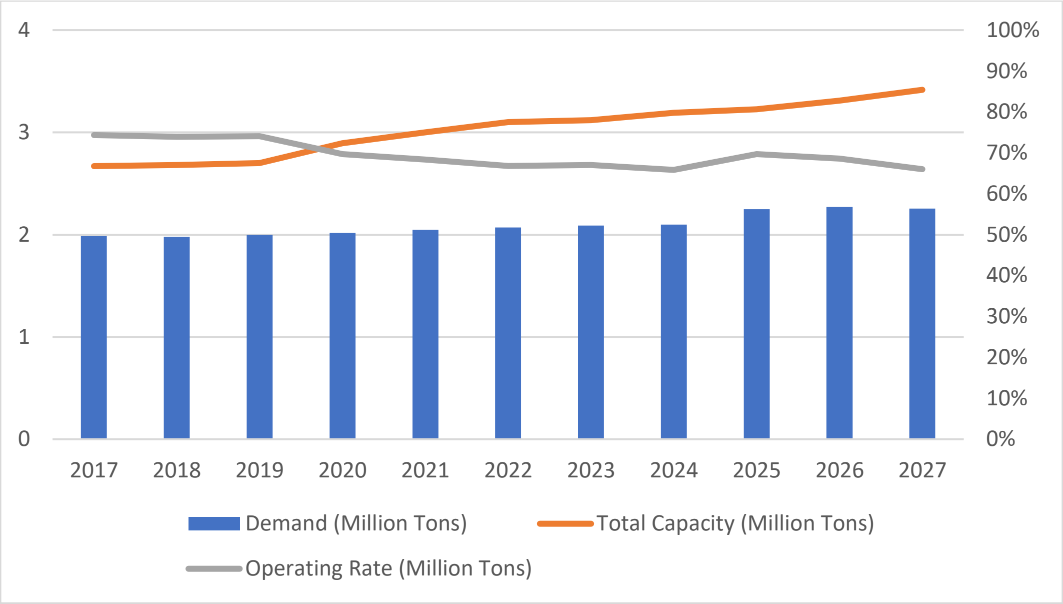
Figure 17- Methylamine Demand by Derivatives



Source: IHS Markit

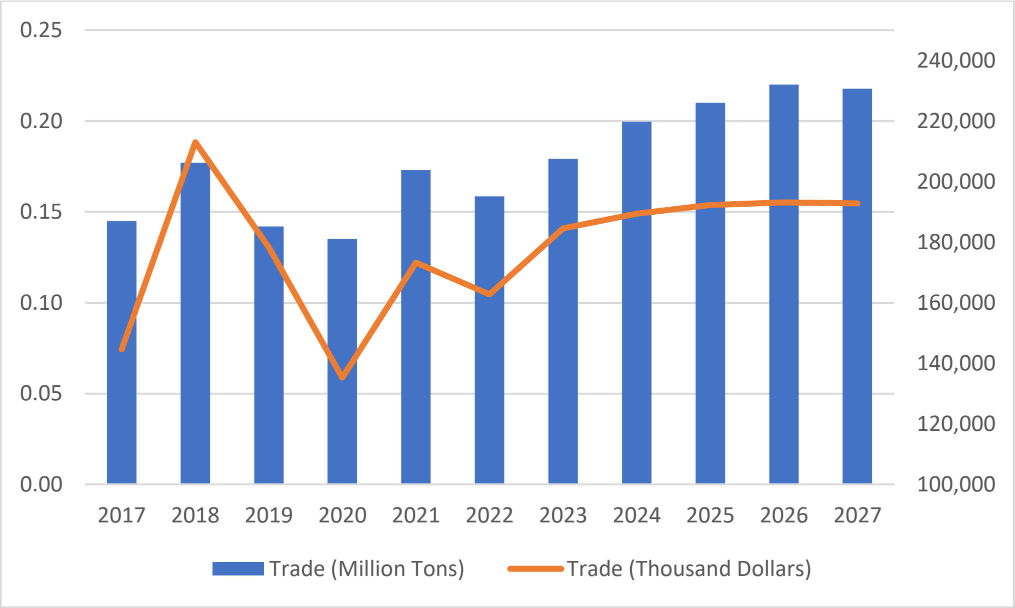
Product Name: Methylamine	
Global Market	
Production capacity: 2.8 million tons per year	**Total Consumption:** 2.018 million tons per year
Major Producing Countries and Regions: North-East Asia	**Major Consuming Countries and Regions:** China
World trade: 173,000 tons per year	
Major Exporters: Belgium, South Korea, USA	**Major Importers:** India, France, Spain
Forecast (2027)	
Production capacity: 3.416 million tons per year	**Total Consumption:** 2.254 million tons per year
Major Producing Countries and Regions: North-East Asia	**Major Consuming Countries and Regions:** China
World trade: 217,000 tons per year	
Major Exporters: Belgium, USA	**Major Importers:** India
Insight: Increase in demand for food grains due to the growing population has boosted agricultural production. This is driving the demand for various agrochemicals including pesticides, herbicides, insecticides, and fungicides. In turn, this is boosting the global methylamine market. Rise in demand for ammonium sulfate in pharmaceuticals, oil & gas treatment, electronics, fuel additives, and other industries is expected to drive the global methylamine market during the forecast period. Increase in usage of methylamine in agricultural applications is expected to boost the market during the forecast period. Methylamine is widely used to manufacture pesticides, insecticides, herbicides, and various other agrochemicals. Growth in the agrochemicals industry is driving the global methylamine market. Dearth of universal directives pertaining to applications of methylamine is expected to restrain the market during forecast period. Every country has different directives pertaining to applications of Methylamine. Companies find it difficult to deal with these country-wise regulations. This is discouraging investment in the methylamine market, thereby restraining the market.	

Figure 18- Methylamine Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 19- Methylamine WorldTrade Trend and Forecast

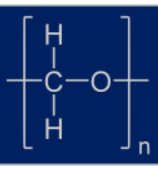


Source: ITC

2-7- Polyacetal

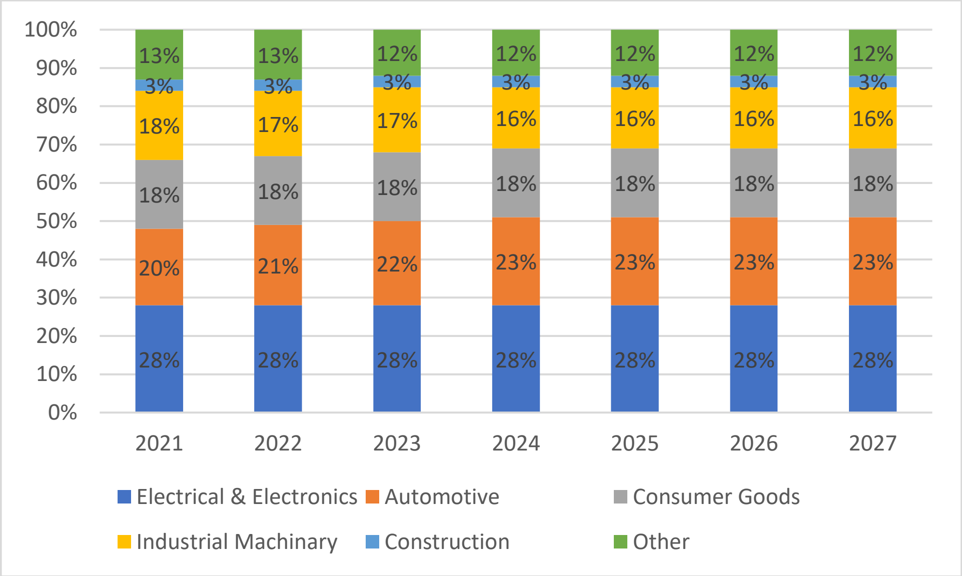
2-7-1- Product Introduction

Table 7- Table of characteristics of Polyacetal

	
Chemical formula	$(CH_2O)_n$
Molar mass	Variable
Appearance	Colorless solid
Density	1.41–1.42 g/cm^3
Melting point	165 °C (329 °F)
Electrical resistivity	14×10^{15} Ω·cm

2-7-2- Market

Figure 20- Polyacetal Demand by Application



Source: IHS Mrkit

Figure 21- Polyacetal Supply and Demand Trend and Forecast

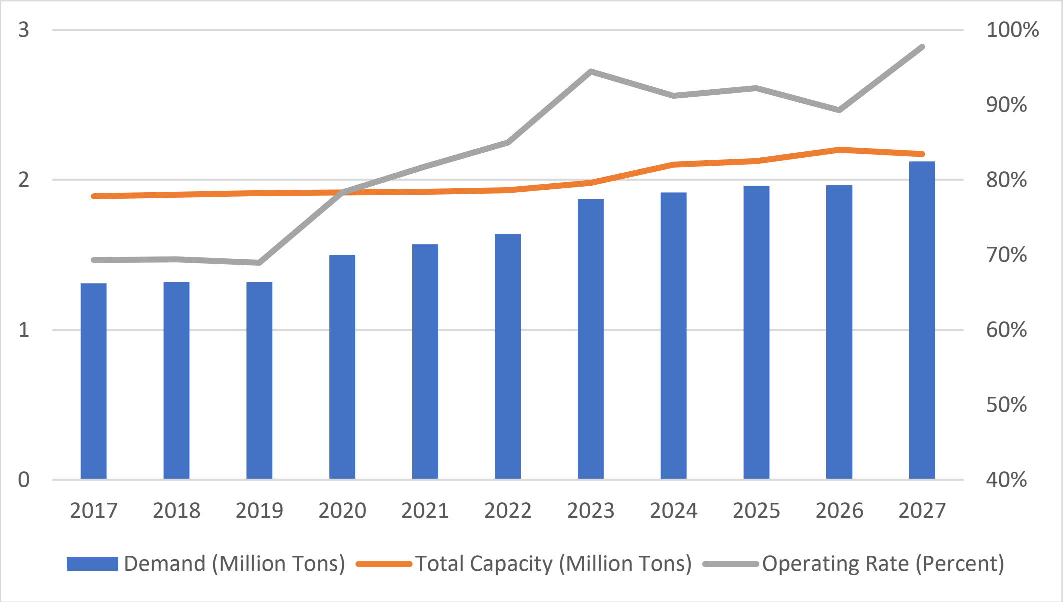
Product Name: Polyacetal (Polyoxymethylene)	
Global Market	
Production capacity: 1.92 million tons per year	**Total Consumption:** 1.57 million tons per year
Major Producing Countries and Regions: North-East Asia, West Europe	**Major Consuming Countries and Regions:** China
World trade: 1.2 million million per year	
Major Exporters: South Korea, Germany, Malaysia	**Major** Importers**:** Trinidad & Tobago
Forecast (2027)	
Production capacity: 2.17 million tons per year	**Total Consumption:** 2.12 million tons per year
Major Producing Countries and Regions: North-East Asia	**Major Consuming Countries and Regions:** China
World trade: 1.38 million tons per year	
Major Exporters: Germany, South Korea	**Major Importers:** Trinidad & Tobago

Insight:

Polyoxymethylene (POM) is a thermoplastic that has various engineering properties such as high stiffness, low friction, and excellent dimensional stability used for making precise medical equipment, automotive parts, electronics components, and consumer goods. Different chemical firms manufacture POM with a few formula changes and market using various trade names like Derlin, Duracon, etc.

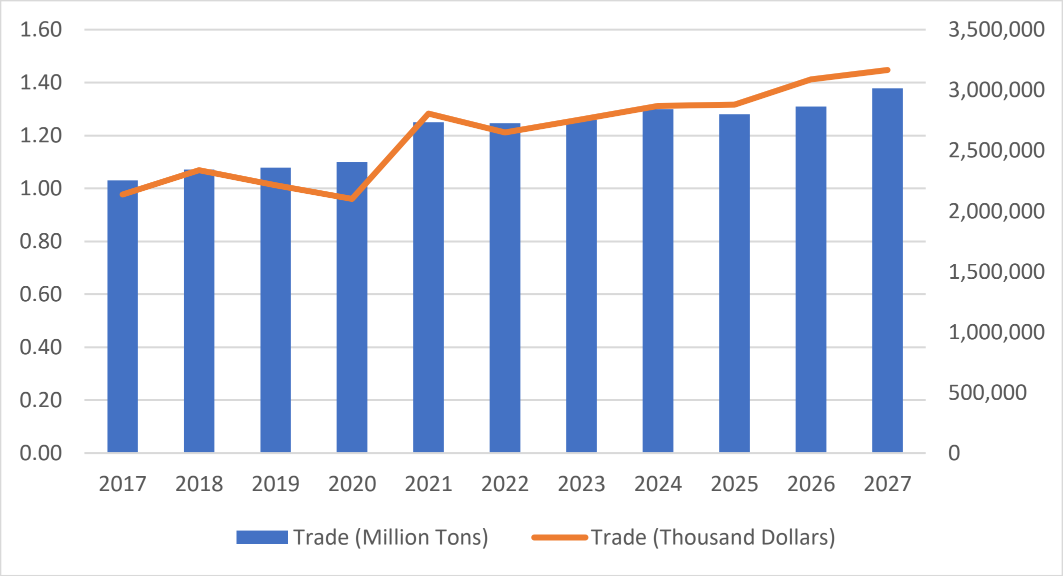
The growing use of polyoxymethylene in the electrical & electronics industry is because of their thermal and insulation properties and excellent durability. Numerous applications regarding the use of POM are circuit boards, switches, electrical housing, wiring, sockets, connectors, and cooling systems. They make mass production more cost-efficient and thus fetching more profits for the manufacturers. The use of polyoxymethylene makes the electronic appliances more lightweight and offers a much better reduction in heating of appliances which in turn increases the life and durability of the products.

Stringent government norms regarding CO2 emission have made automobile manufacturers to reduce overall vehicle weights. The use of polyoxymethylene (POM) in manufacturing various automotive parts significantly reduces the overall weight of the vehicle which helps in the reduction of emissions and makes it more economical. The recent increase in the R&D expenditures in the electrical automobile industry has helped boost the global polyoxymethylene market share since it makes the vehicle more affordable and lightweight.



Source: IHS Markit

Figure 22- Polyacetal Supply and Demand Trend and Forecast

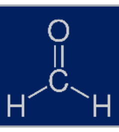


Source: ITC

2-8- Formaldehyde

2-8-1- **Product Introduction**

Table 8- Table of characteristics of Formaldehyde

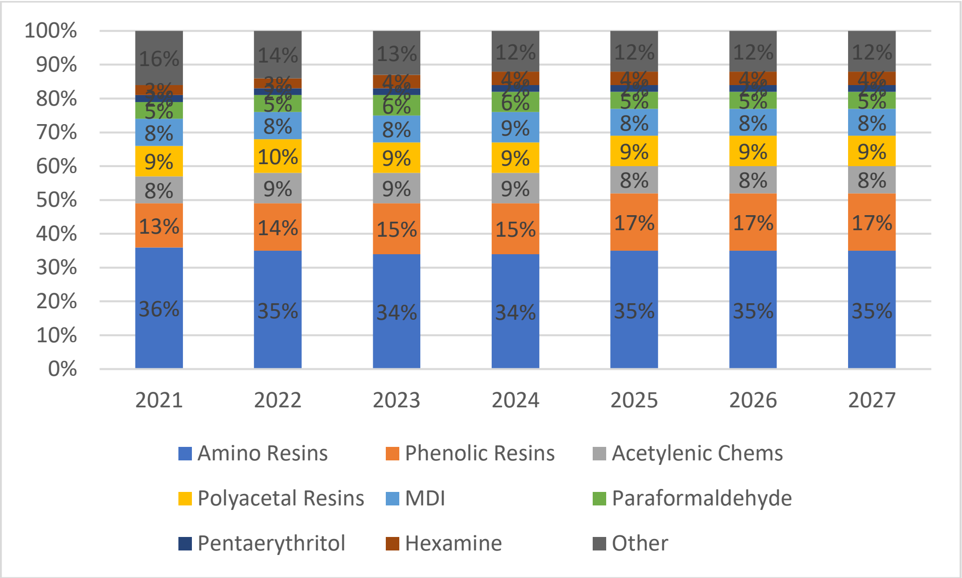
	
Chemical formula	CH_2O
Molar mass	30.026 g·mol^{-1}
Appearance	Colorless gas
Density	0.8153 g/cm^3 (−20 °C) (liquid)
Melting point	−92 °C (−134 °F; 181 K)
Boiling point	−19 °C (−2 °F; 254 K)

2-8-2- **Market**

Formaldehyde is the major end-use derivative of methanol globally. It has contracted to about 27 percent of global demand as new end-uses such as conversion to olefins have increased. The main derivatives of formaldehyde include the following:

- Amino resins (Urea-, Melamine-, and Melamine-Urea-Formaldehyde resins)
- Phenolic resins (Phenol-Formaldehyde resins)
- Polyacetal resins
- Acetylenic chemicals (via conversion of formaldehyde to butanediol)
- Methylene Diphenyl Diisocyanate (MDI)
- Hexamine
- Paraformaldehyde

Figure 23- Formaldehyde Demand by Application



Source: IHS Markit

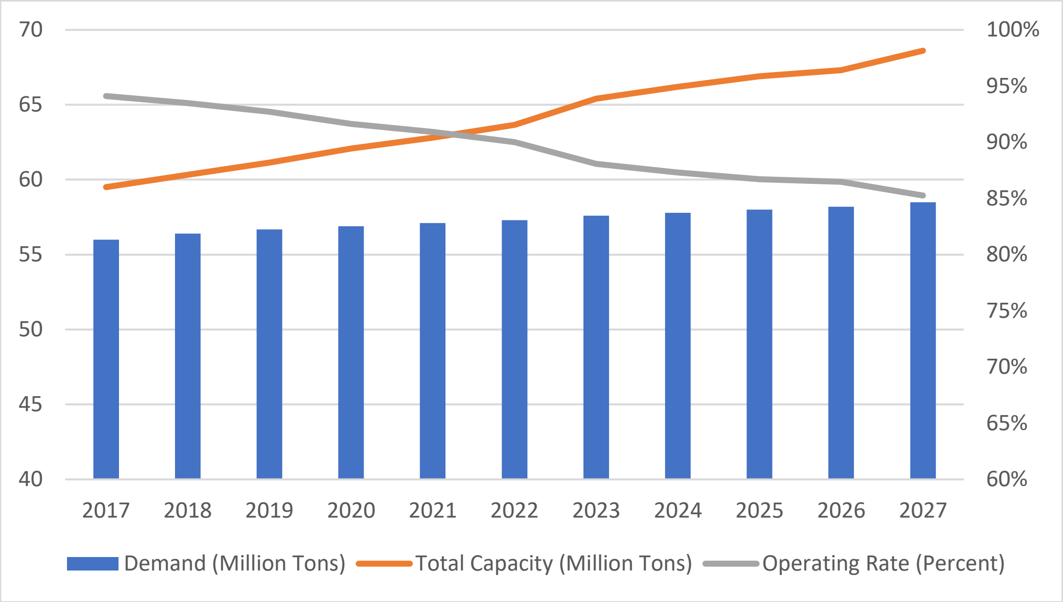
Product Name: Formaldehyde	
Global Market	
Production capacity: 62.8 million tons per year	**Total Consumption:** 57.1 million tons per year
Major Producing Countries and Regions: North-East Asia	**Major Consuming Countries and Regions:** China
World trade: 493 thousand tons per year	
Major Exporters: Netherland, Italy	**Major** Importers**:** Germany,Trinidad & Tobago
Forecast (2027)	
Production capacity: 68.6 million tons per year	**Total Consumption:** 58.4 million tons per year
Major Producing Countries and Regions: North-East Asia	**Major Consuming Countries and Regions:** China
World trade: 555 thousand tons per year	
Major Exporters: Netherland	**Major Importers:** Germany

Insight:

In terms of value, the global formaldehyde market is expected to surpass US$ 15 Bn by **2027**, expanding at a CAGR of **~4%** during the forecast period Formaldehyde is a chemical compound produced by the oxidation of methanol. Methanol is the primary raw material used in the formulation of formaldehyde. Formaldehyde is an important component for the production of urea-alkyd resins, which are used largely for the output of binding materials for particleboards and medium density plywood. Formaldehyde is widely used in various industries such as plywood, automobile, and construction.

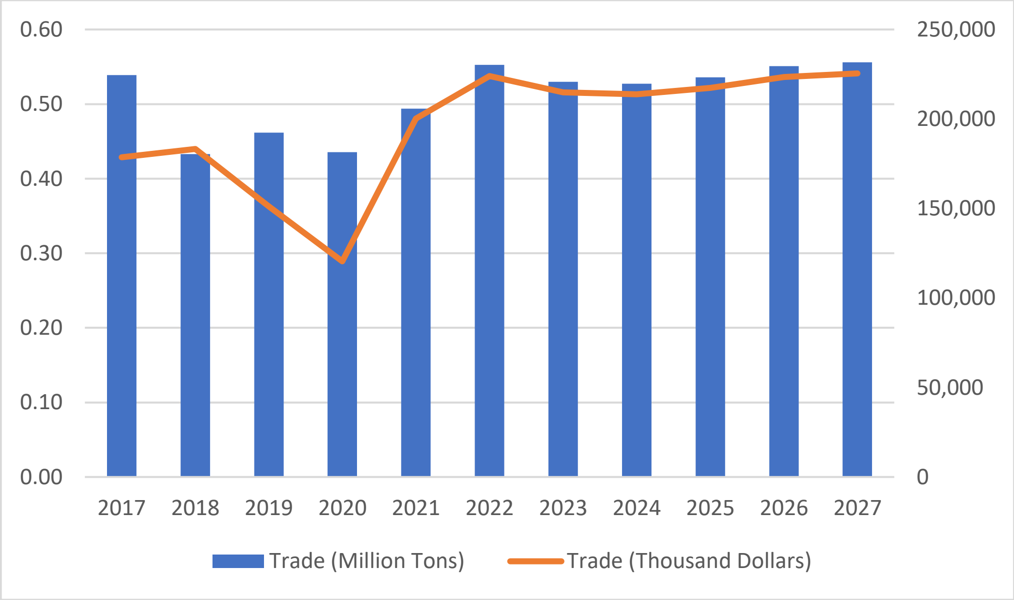
Growth of the building & construction industry and continuous demand for formaldehyde in the furniture sector are driving the global formaldehyde market. Formaldehyde is primarily used to produce wood panels and adhesives. Formaldehyde-based resins are used in construction and furniture sectors due to their strong adhesive strength and moisture resistance properties.

Figure 24- Formaldehyde Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 25- FormaldehydeWorld Trade Trend and Forecast

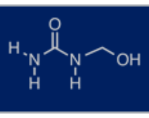


Source: ITC

2-9- Urea-Formaldehyde

2-9-1- **Product Introduction**

Table 9- Table of characteristics of Urea-Formaldehyde

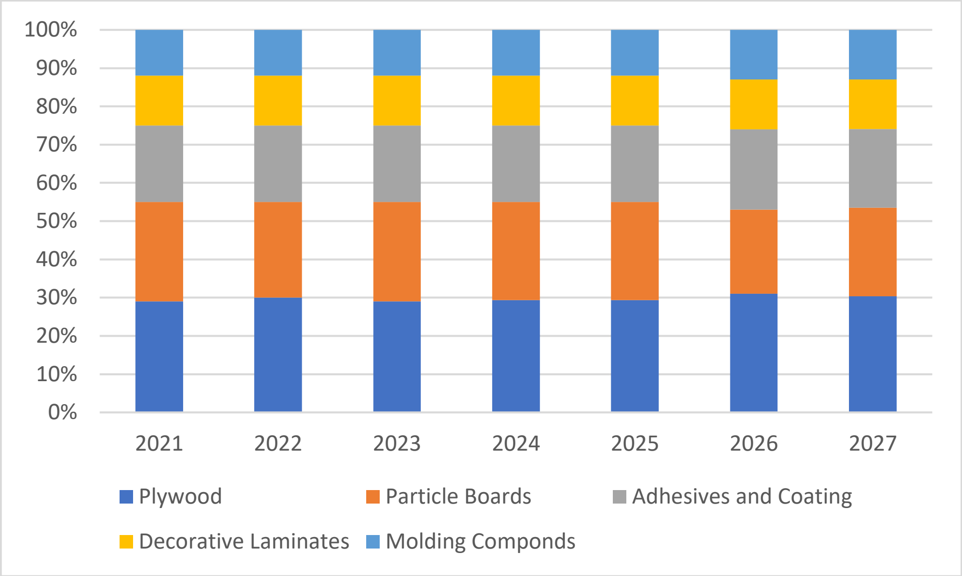
	
Chemical formula	C2H6N2O2
Viscosity	1,700 – 2,500 cPS (at 30°C)
Appearance	White powder
pH	8.0 – 9.0 (at 30°C)

2-9-2- **Market**

Urea-formaldehyde (UF) resins represent the single largest market for formaldehyde, accounting for about80 percent of the global demand for amino resins. UF resins are primarily used as adhesives in the wood panel industry due to their tendency to harden rapidly at moderate temperatures. Some of the key advantages of UF resins are shown below:

- Heat resistance
- Solvent and chemical resistance
- High tensile strength
- Surface hardness
- High reactivity
- Resistance to microorganisms
- Resistance to degradation by light.
- Relatively low material costs (methanol, urea)

Figure 26- Urea-Formaldehyde Demand by Application



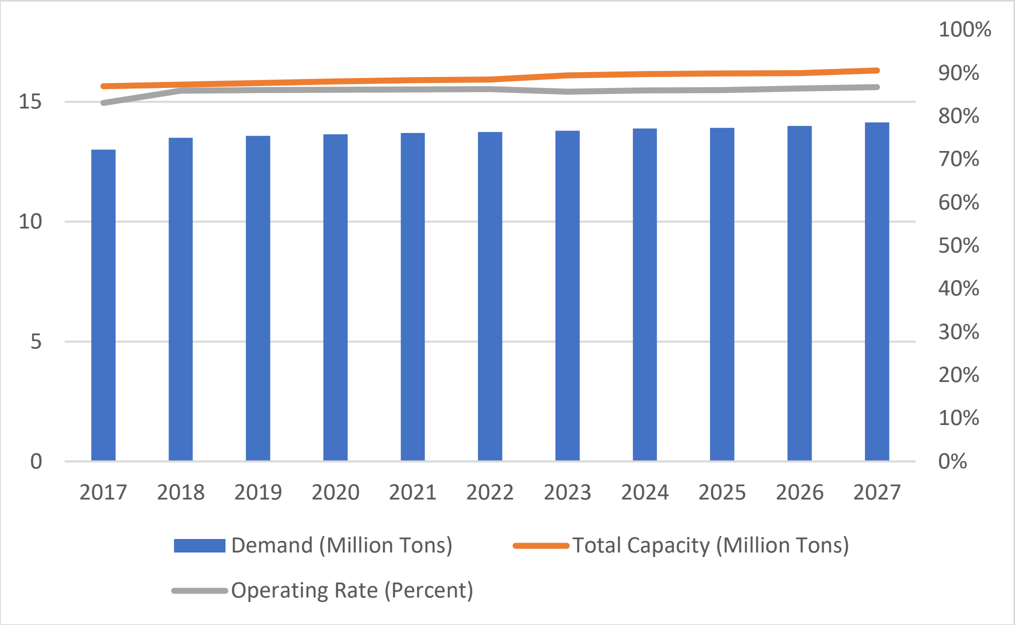
Source: Market Research Future

Product Name: Urea-Formaldehyde	
Global Market	
Production capacity: 15.9 million tons per year	**Total Consumption:** 13.7 million tons per year
Major Producing Countries and Regions: North-East Asia	**Major Consuming Countries and Regions:** China
World trade: 5.94 million tons per year	
Major Exporters: Trinidad & Tobago, Germany	**Major Importers:** Germany, France
Forecast (2027)	
Production capacity: 16.3 million tons per year	**Total Consumption:** 14.14 million tons per year
Major Producing Countries and Regions: North-East Asia	**Major Consuming Countries and Regions:** China
World trade: 6.18 million tons per year	
Major Exporters: Trinidad & Tobago	**Major Importers:** Germany

Insight:

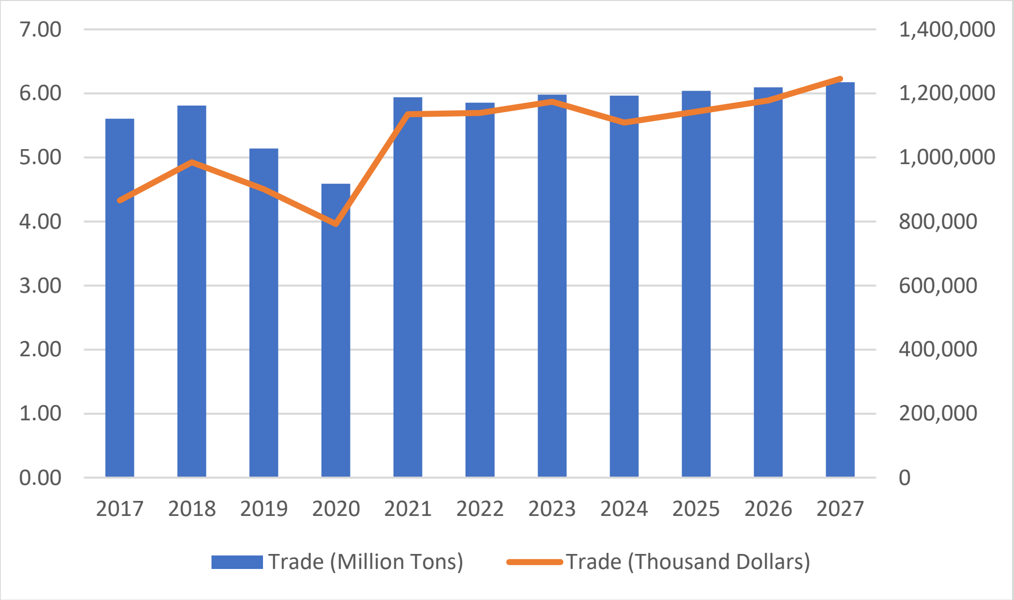
The market of Urea Formaldehyde witnessed a CAGR of 3.3% over the historical period of 2016 and 2021. Significant growth in various end-use industries, such as automobiles, furniture, and the construction sector, combined with increased awareness about the numerous benefits of urea formaldehyde, has resulted in increased demand for urea formaldehyde over time. Considering the industries served, consumption of urea formaldehyde is uneven, which has stifled its demand. However as per the current survey conducted by FMI, the forecast growth outlook for the Urea Formaldehyde is to remain around 4.4% for the period of 2022 and 2032. South Asia Pacific countries such as China, Japan, India, and Australia are expected to witness a substantial demand for urea formaldehyde in the coming years specifically from automotive and construction industries.

Figure 27-Urea- Formaldehyde Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 28-Urea- Formaldehyde World TradeTrend and Forecast

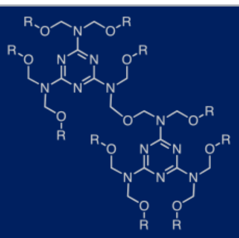


Source: ITC

2-10- Melamine-Formaldehyde

2-10-1- Product Introduction

Table 10- Table of characteristics of Melamine-Formaldehyde

	
Chemical formula	$C_4H_8N_6O_2$
Viscosity	300 – 500 mPa.s (at 23°C)
Appearance	White powder
pH	7.0 – 9.0 (at 30°C)

2-10-2- Market

Melamine-formaldehyde (MF) resins are generally more expensive than UF resins due to their e

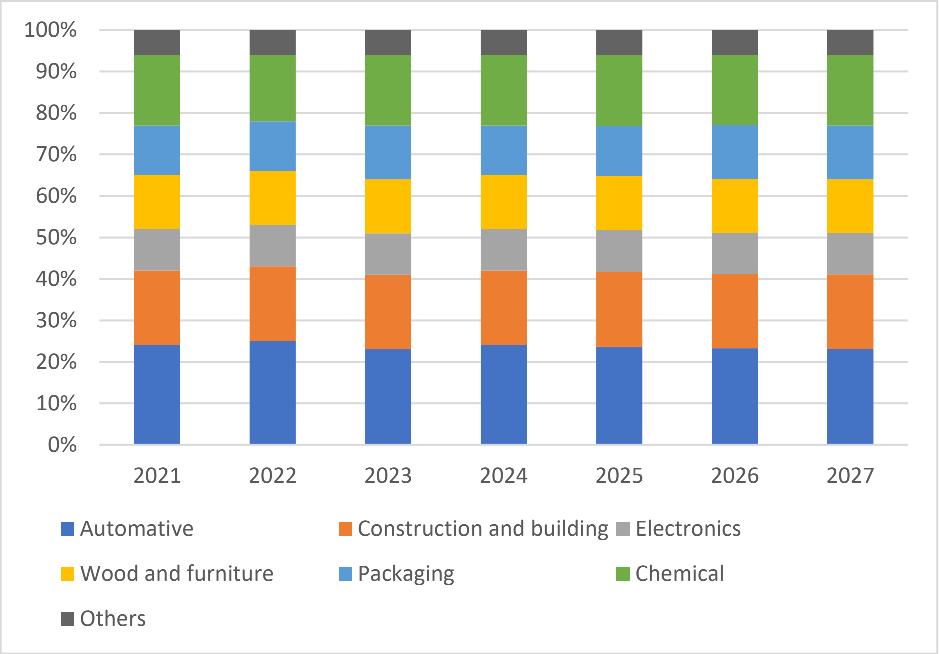
nhanced properties, which include the following:

- Better hardening properties
- Higher mechanical strength
- Greater resistance to electrical tracking
- Greater resistance to moisture

Other key properties include:

- Good appearance
- Thermal stability
- Stain resistance
- Durability
- Emit less formaldehyde than urea resins

Figure 29- Melamine-Formaldehyde Demand by Application



Source: Market Research Future

Product Name: Melamine-Formaldehyde	
Global Market	
Production capacity: 5.7 million tons per year	**Total Consumption:** 4.6 million tons per year
Major Producing Countries and Regions: North-America	**Major Consuming Countries and Regions:** North-East Asia
World trade: 493 Thousand tons per year	
Major Exporters: Germany, China	**Major Importers:** France,Germany, Italy
Forecast (2027)	
Production capacity: 5.8 million tons per year	**Total Consumption:** 4.7 million tons per year
Major Producing Countries and Regions: North-America	**Major Consuming Countries and Regions:** North-East Asia
World trade: 516 Thousand tons per year	
Major Exporters: Belgium	**Major Importers:** France

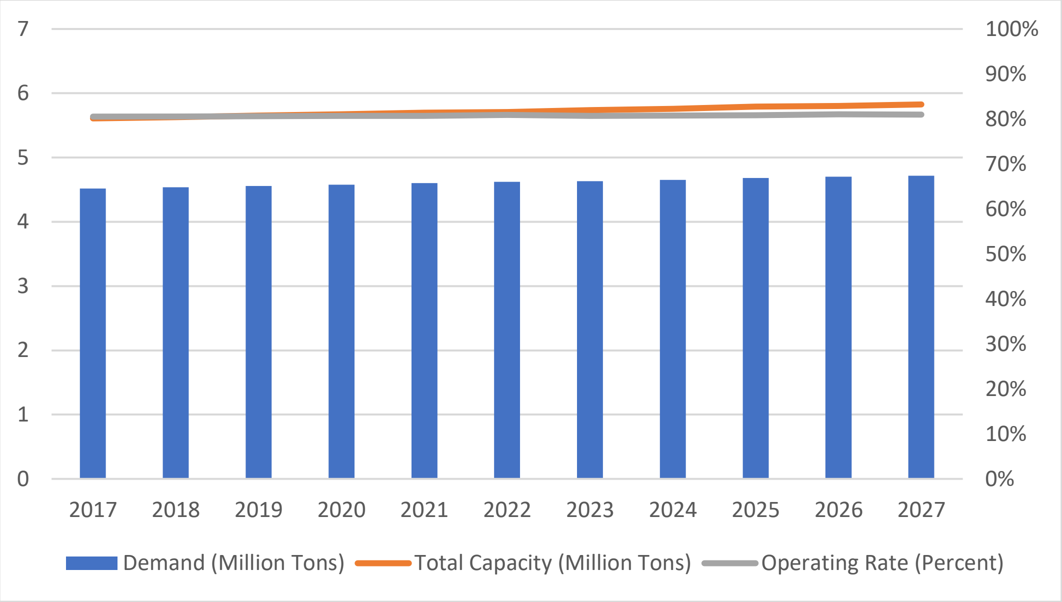
Insight:

The Melamine Formaldehyde Market occupies a CAGR of 6.5% and is expected to reach a market value of USD 118.03 Billion during the forecast.

Melamine formaldehyde, often known as melamine resin, is made by polymerizing formaldehyde and melamine. Because it is a thermosetting plastic with a net-like structure and cross-linked polymers, it is the toughest polymer. It is not feasible to remold or melt it, as it has been subjected to chemical alterations throughout the operation. Moisture resistance, hardness, weather resistance, temperature resistance, and other characteristics are among the most important. Melamine formaldehyde is a synthetic resin made from the condensation of two monomers: melamine and formaldehyde. Melamine formaldehyde is heat and fire-resistant thermosetting aminoplast that is resilient, rigid, and flexible. Particleboard and plywood adhesives, laminated tabletops and countertops, automotive surface coatings, and dishwasher-safe tableware all use this chemically resistant resin. Melamine formaldehyde contains a lot of nitrogen. Melamine sublimation absorbs a significant amount of heat energy and is hence employed as a heat sink in fire scenarios. As a result, melamine-formaldehyde can be used instead of halogen-based flame retardants. It is mostly found in specialty paints, textiles like firefighting gear, and flexible urethane foam, which is utilized in the bedding industry, as well as furniture and electronics. Asia Pacific holds a major share of the market due to the growing demand for Melamine Formaldehyde polymers in automotive, construction and building, electronics, and others. The construction and buildings segment is predicted to witness a rapid growth in the market due to increasing consumption of formaldehyde resins in countries such as China, Japan and India. It is estimated that the

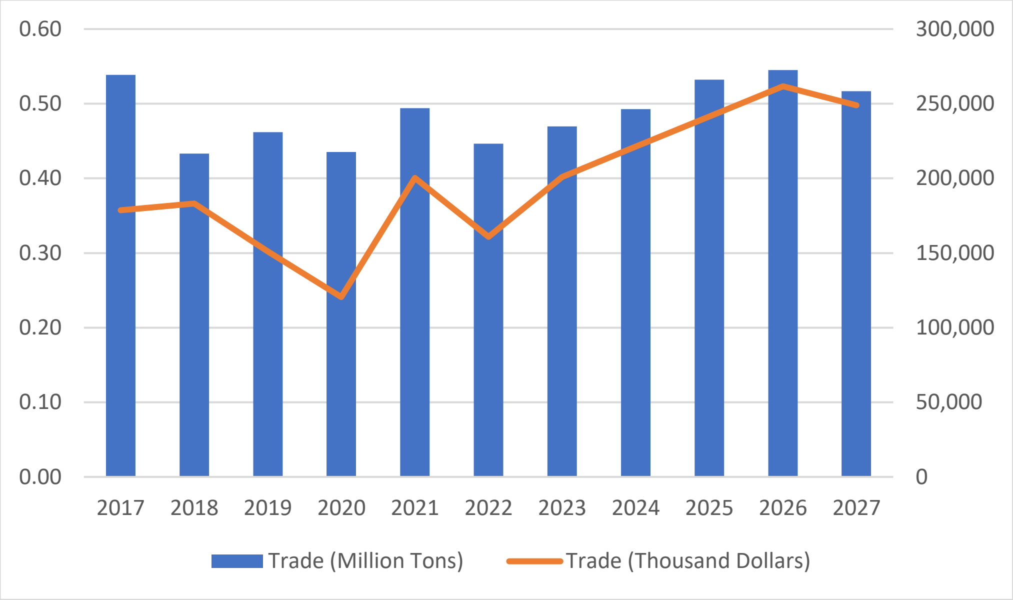
automotive segment is set to witness a higher growth in the market during the forecast period.

Figure 30- Melamine- Formaldehyde Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 31- Melamine- Formaldehyde World Trade Trend and Forecast

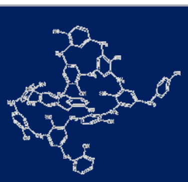


Source: ITC

2-11- Phenol-Formaldehyde

2-11-1- Product Introduction

Table 11- Table of characteristics of Phenol-Formaldehyde

	
Chemical formula	C7H8O2
Molecular Weight	134.13
XLogP3	2.1
Hydrogen Bond Donor Count	1
Hydrogen Bond Acceptor Count	2
Rotatable Bond Count	1
Exact Mass	134.036779430

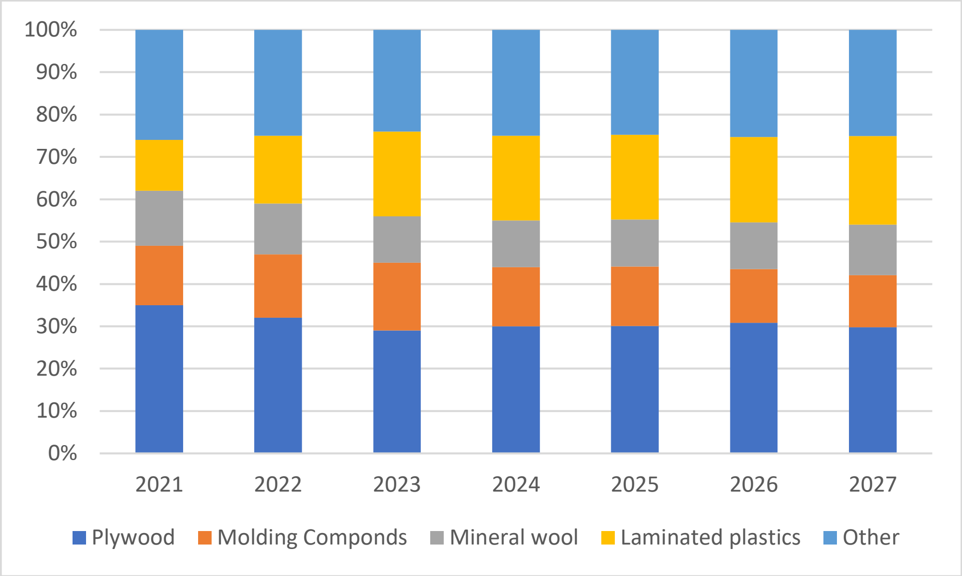
2-11-2- Market

Phenol-formaldehyde (PF) resins were initially introduced to the market as Bakelite in 1910. PF resin production is the second largest market for formaldehyde. The unique properties of these resins have allowed them entry into a wide variety of product applications. Their key properties are listed below:

- High bonding strength
- Hardness
- High temperature performance
- Chemical resistance
- Produce low amount of smoke with low levels of toxicity
- Higher char yield than other plastic materials when exposed to temperatures above their point of decomposition

Emit less formaldehyde than urea resins

Figure 32- Phenol-Formaldehyde Demand by Application



Source: Market Research Future

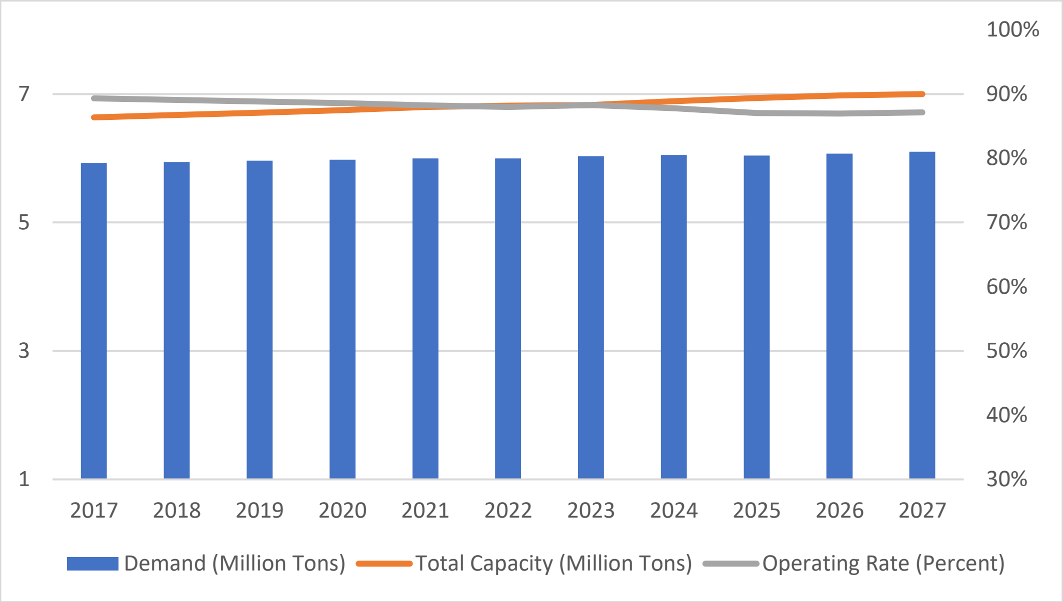
Product Name: Phenol-Formaldehyde	
Global Market	
Production capacity: 6.8 million tons per year	**Total Consumption:** 6 million tons per year
Major Producing Countries and Regions: USA	**Major Consuming Countries and Regions:** USA
World trade: 1.1 Million tons per year	
Major Exporters: USA, China, Germany	**Major Importers:** China, Canada ,Germany
Forecast	
Production capacity (2027): 7 million tons per year	**Total Consumption:** 6.1 million tons per year
Major Producing Countries and Regions: USA	**Major Consuming Countries and Regions:** USA
World trade: 1.12 Million tons per year	
Major Exporters: USA	**Major Importers:** China

Insight:

Phenol formaldehyde adhesives are used in wooden chipboard for exterior wall appellations as they offer moisture resistance. In the construction industry, phenol formaldehyde resins are used as wood adhesives and glues for construction grade wood panels. Phenol formaldehyde adhesives offer high moisture resistance and superior water resistance. Phenol formaldehyde reacts with natural phenol-like lignin found in wood to enhance glue to wood bond and sets hard and rigid. Therefore, demand for phenol formaldehyde adhesives from the construction industry is also expected to boost the market growth over the forecast period.

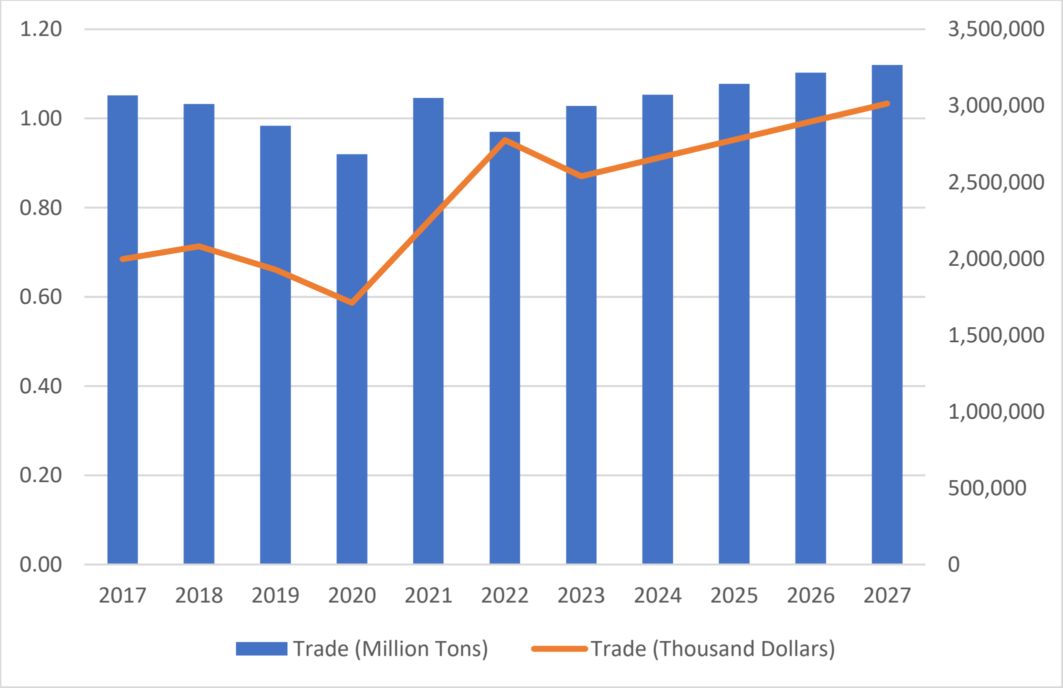
The market in Asia Pacific is expected to hold dominant position over the forecast period. This is attributed to growing building and construction industry in the economies of India and China. The market is also expected to witness the fastest growth over the forecast period, owing to increasing demand for phenol formaldehyde adhesives and laminates in this region. The market in North America is primarily driven by high demand of phenol formaldehyde adhesives and laminates from the construction and wooden chipboard market. The market in Europe is expected to account for significant market share, owing to high demand for phenol formaldehyde adhesives and laminates from Germany followed by Italy, Spain, Sweden, and the U.K.

Figure 33- Phenol- Formaldehyde Supply and Demand Trend and Forecast



Source: IHS Markit

Figure 34- Phenol- Formaldehyde World Trade Trend and Forecast



Source: ITC

3- Technical Assessment

3-1- LDPE

LDPE technology was first developed in the late 1930s. It has since grown to include ethylene homopolymers, copolymers, and modified ethylene homo/copolymers with specific gravities in the range of 0.915 to 0.935. In this chapter, the selected process of LDPE production will be reviewed.

The selected process for the production of LDPE is the LupotechTM T high pressure tubular reactor process belonging to the Basel Company, which is described below.

This plant is divided into three parts in terms of process:

• Section 100: Polymerization Section

• Section 200: Recovery Section

• Section 300: The final Section

➢ Section 100: Polymerization Section

In the polymerization Section, ethylene is polymerized with a mixture of peroxide initiators in a jacketed tubular reactor, R-101, which has a preheating zone. Fresh ethylene is combined with low pressure recycle gas E-206 (stream 13) in surge tank V-101. The mixture is sent to the K-101 primary compressor, which increases the mixture pressure from 250 psi (17.2 bar) to 4352 psi (300 bar). A small amount of the compressed stream from K-101 (Stream 4) is mixed with a chain transfer agent in V-104. Most of the compressed stream is cooled to 105°F (41°C) in the E-103 cooler. A part of the cooled stream is fed downstream of the reactor pressure reduction valve as a low pressure quencher (stream 6). The remaining cooled stream in surge tank V-103 is combined with high-pressure recycle gas V-204 (stream 9). This mixture (stream 5) is compressed to 45,000 psi (3,100 bar) in the K-102 hypercompressor. The compressed flow from K-102 is divided into two parts. One portion is fed to the front end (preheating zone) of the R-101 reactor. The remaining ethylene feed from K-102 is separated into five streams, cooled in cooler E-106A-D, and fed to the reactor with initiators at various points, as shown in the flow diagram.

The reactor consists of a preheating zone and several reactor zones. In the preheating zone, the temperature of the reaction mixture rises to about 320°F (160°C). Downstream of the preheating zone, the reactor is divided into five reaction zones. A mixture of ethylene and initiators is added at the beginning of each reaction zone. The chain transfer agent (propionaldehyde) diluted in a

small amount of ethylene is fed to the reactor independently from the K-103 compressor. Immediately after each zone is a cooling zone. Water at about 302°F (150°C) is circulated through the reaction zone jacket to control the reaction temperature. Heat release in the reaction zone is partially removed as 50 psig steam. The residual heat released causes the reaction temperature to rise to about 581°F (305°C). In the cooling zone, the reactor is cooled with cooling water through the reactor jacket.

The polymer tends to accumulate on the water-cooled walls. The use of higher temperature cooling water, 302°F (150°C), in the reaction zone has a greater tendency to aggregate polymer and maintain turbulent flow in the reaction zone to some extent. Polymer accumulation increases the pressure drop through the reactor. Increasing the pressure drop causes the discharge valve to open and the polymer is drawn from the walls into the main stream. This action creates periodic pressure pulses. Detection of an early runaway reaction also results in rapid opening of the relief valve. The outlet stream leaves the reactor at about 500°F (260°C). Reactor effluent is combined with low pressure cold quench (6). With the expansion downstream of the reactor shut-off valve, the temperature increases due to the inverse Joule-Thompson effect. Low pressure shutdown at 105°F (41°C) minimizes temperature rise.

- Section 200: Recovery Section

The reactor effluent is pressurized in two stages. In the first stage, the pressure is reduced from about 39,400 psi (2,717 bar) to about 4,351 psi (300 bar). In the high pressure separator V-201, the effluent is separated into a molten polymer phase and a gas phase. Most of the unreacted ethylene is recovered from the high pressure separator and fed to the high pressure recycle circuit. This stream contains small amounts of low molecular weight waxes, which are removed by successive cooling (E-201A&B, E-202A&B, and E-203A&B) and each by phase separation in separators (V-202, V-203, and V -204). The wax-free high-pressure ethylene stream (9) is recycled to the suction end of the K-102 hypercompressor.

The molten polymer phase from V-201 is fed to the low-pressure separator V-206, which is at 10 psig (0.7 bar). A low-pressure recycle gas (12) exits V-206, is cooled in E-204, fed to surge tank V-207, and then compressed to about 290 psi (20 bar) in the purge gas compressor. A small part of this stream is discharged to the ethylene plant to control the amount of inert gas in the process loop. The residue is recycled to the V-101 surge tank and then fed to the K-101 primary compressor suction. From the bottom of the V-206 low pressure separator, the polymer melt is sent to the product finishing Section.

- Section 300: The End Chapter

The V-206 highly viscous polymer melt is fed directly into the G-301 hot melt evaporating extruder line. The remaining monomer is removed through a vacuum valve. Additives may be added to the extruder. Downstream of the extruder screw, the hot melt is fed through a startup diverter, gear pump, plate changer, and then to the tabletting die. Then the pellets are dried, cooled and classified. The pellets are transferred to the S-303A-G storage silos and/or to the S-304A-G and S-305A-G loading and packing silos.

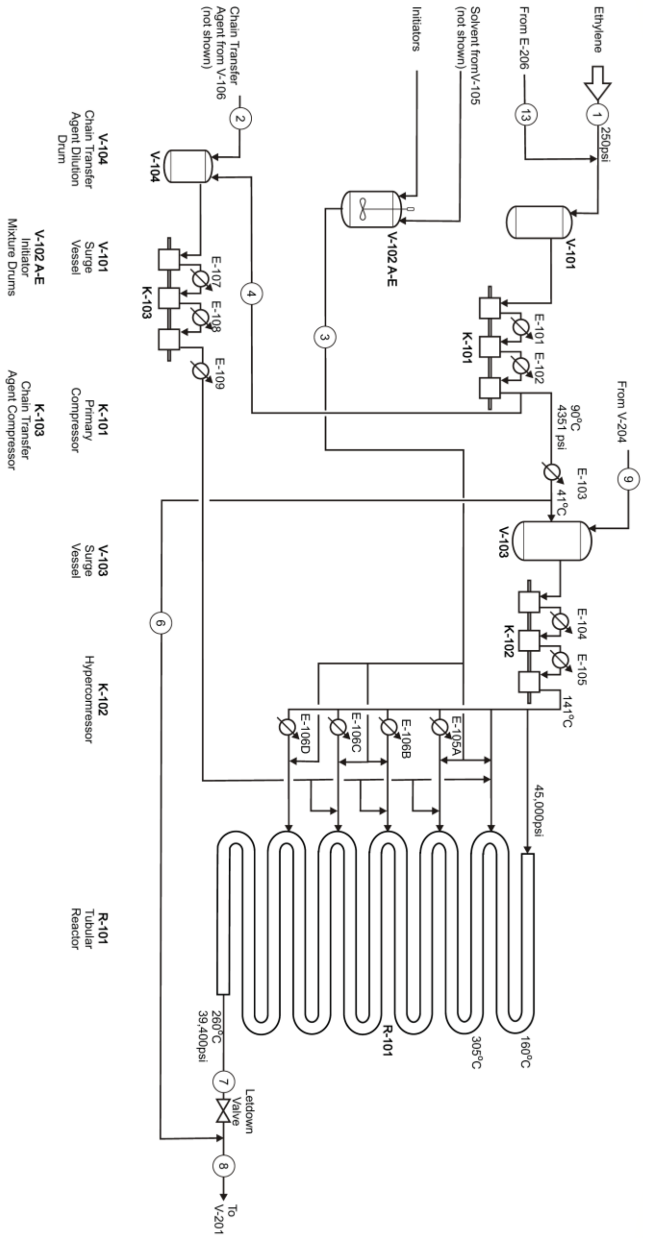


Figure 35- Section 100 Diagram

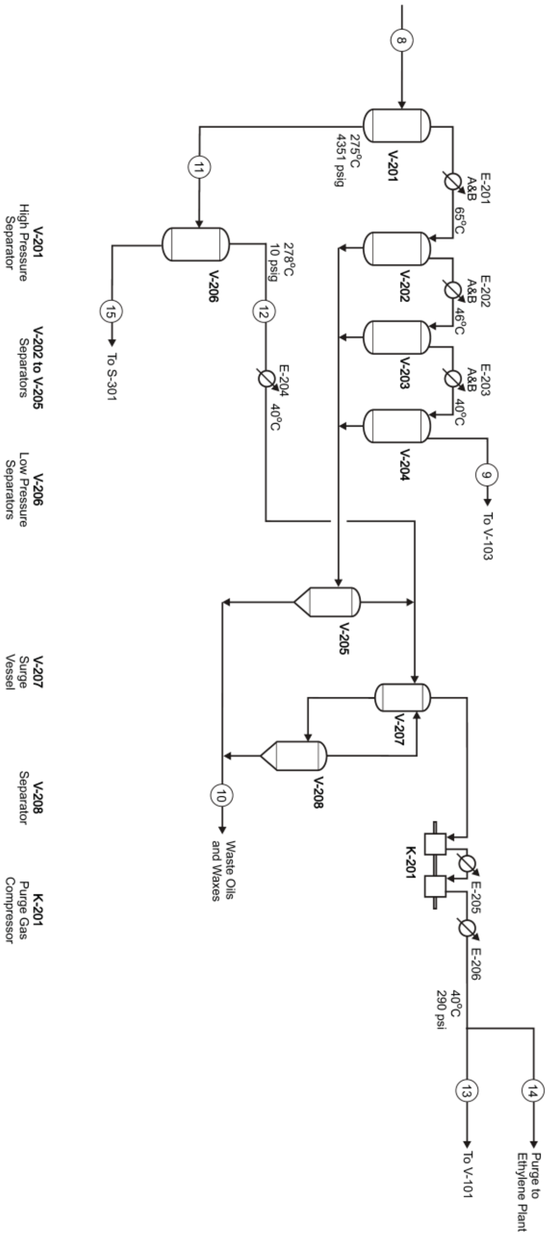


Figure 36- Section 200 Diagram

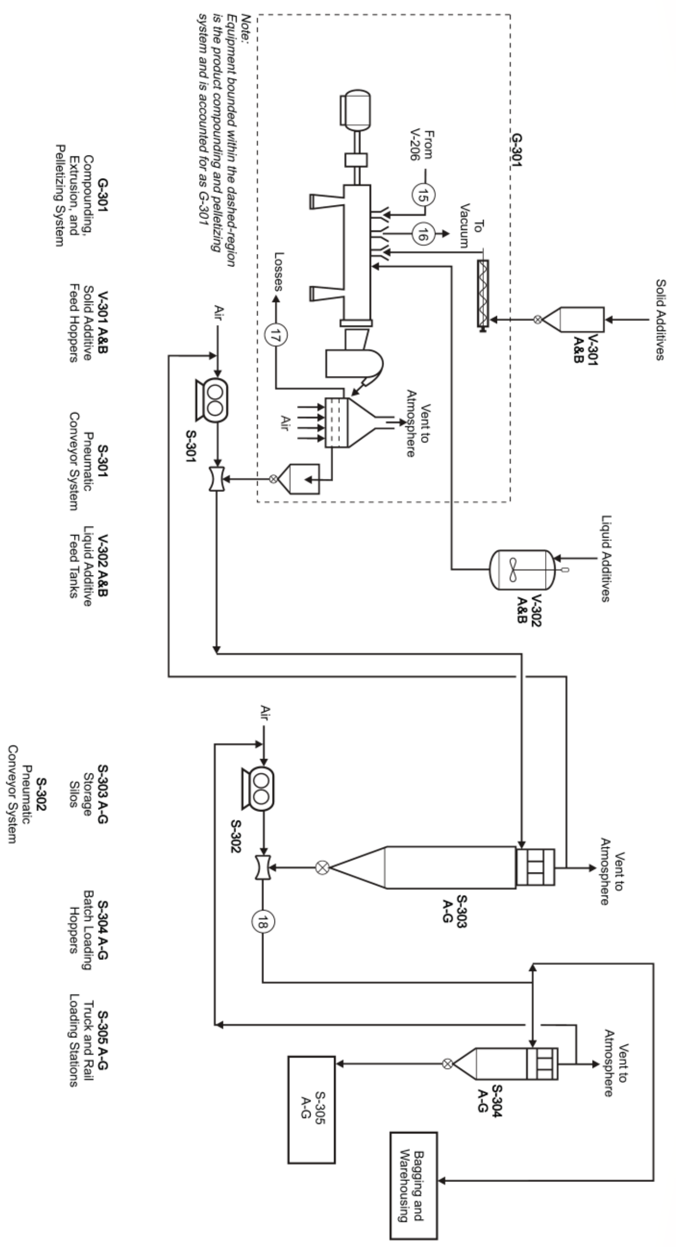


Figure 37- Section 300 Diagram

3-2- Synthesis gas production Section (HYCO)

Synthesis gas is a gaseous mixture of hydrogen, carbon monoxide, and more often, carbon dioxide. This gas may be used as a fuel, but its main use and importance is as a raw material for a wide range of high-value chemicals and environmentally friendly fuels. The main sources of synthesis gas are coal, natural gas, naphtha, refinery residues and to some extent biomass from which gas can be produced by various reforming processes. The main reforming technologies include methane steam reforming, non-catalytic partial oxidation, catalytic partial oxidation and autothermal reforming.

The following tables compare the operating conditions and other technical specifications of synthesis gas production technologies. Considering that in this plan, the goal of synthesis gas production is to produce CO, the selected synthesis gas production process in this report is the non-catalytic partial oxidation process of POX.

Figure 38- Comparison of operating conditions and other characteristics of four synthesis gas production processes

	SMR	POX	CPOX	ATR
Temperature, °C	800–900°C	1,000–1,450°C	800–1,000°C	850–1,300°C
Pressure, bar	20–30	30–85	15–40	20–70
H_2/o ratio	3–6	1.6–2	1.6–2	1.6–2.5
Methane conversion, %	65–95	95–99	95–99	95–99
Oxygen plant required*	No	Yes	Yes	Yes
Steam consumption	High	Optional	Optional	Low to medium
Capital costs, %	100 (Ref)	80–110	55–80	65–85
Scale	Large	Small to large	Small to large	Large
Development status	Commercial	Commercial	Precommercial	Commercial

* Air can also be used instead of oxygen in POX, CPOX, and autothermal reforming.

Figure 39- Comparison of technical advantages and disadvantages of synthesis gas production technologies

Table 4.8: Comparison of process technologies for syngas generation used in GTL processing

Pros (+) and cons (-) of various syngas generation approaches

Steam methane reforming (SMR)	Partial oxidation (POX)	Autothermal reforming (ATR)
+ Largest number of units in operation	- Fewer units in operation	- Fewer units in operation
+ No oxygen unit required	- Oxygen required	- Oxygen required†
- Runs at lowest temperature	+ Runs at high temperature	+ Runs at lower temperature than POX
+ No coking	- Coking a problem	- Coking a problem
- Higher H_2 to CO ratio	- Lower H_2 to CO ratio	+ Favorable 1.6–2.65 H_2 to CO
- Needs external heat	+ Makes own heat	+ Makes own heat
- Needs steam	+ No steam*	+ No steam*
- Higher CO_2 produced	+ Lower CO_2 produced	+ Lower CO_2 produced
- CO_2 recycle expensive	+ Low or no CO_2 recycle	+ Low or no CO_2 recycle
- No sulfur can be tolerated	+ Sulfur taken out after	- No sulfur can be tolerated
- Only natural gas feedstock	+ Wide range of feedstocks	- Only natural gas feedstock
- Catalyst required	+ No catalyst	- Catalyst required
- Start/Stop difficult	+ Start/Stop easier	+ Start/Stop easier
- More methane slip	+ Less methane slip	+ Less methane slip

† Syntroleum ATR uses forced air rather than oxygen by passing need for oxygen unit.

* However, steam generally used to reduce coking, but far less than SMR.

Source: Paper presented by Howe-Baker Engineers, Inc. Bob Tindall and Andy Crews at The San Antonio GTL meeting, May 1998. Additional input from Rentech and Syntroleum.

3-3- Acetic Acid

Acetic acid is produced synthetically by several processes and raw materials. Methanol carbonylation is currently the most dominant and popular technology, accounting for about 62% of the world's current active installed capacity. Acetaldehyde oxidation is another major route, mainly used in Europe until recently (the US currently does not operate any production Sections based on this technology). With the closure of the Celanese plants in Germany, it appears that this route is rapidly changing to carbonylation technology even in Europe. Asia is currently the main user of this technology. Oxidation of naphtha, ethanol and n-butane are other sources of acetic acid.

Considering the relatively lower investment and operating cost of the CativaTM process of BP Company compared to the process of CELANESE Company, it is the selected process in this report.

The figure below shows the process flow diagram of the acetic acid production process by the CELANESE method and the table below shows the list of its main equipment. The process consists of two parts:

• Section 100- Carbonylation of methanol.

• Section 200-Refining the product.

- Section 100- Carbonylation of methanol

An electric single-chamber multistage compressor, the K-101A (or K-101B), with interstage coolers, compresses the CO feed gas from its (assumed) supply line pressure of 64.7 psia to 415 psia. The gas enters the bottom of the R-101 reactor through a gas sparger. Also, makeup catalyst solution (stream 3), methanol feed (stream 4), recycle catalyst solution (stream 8) and mixed recycle stream (stream 23) were added to the R-101 reactor. Methanol enters the reactor from the T-101 methanol feed tank. Off-site methanol storage tanks (T-151A-C), not shown in the figure, serve as a means of long-term methanol storage. The methanol feed stream is heated on its way to the R-101 reactor at E-101 by heat exchange with the reactor effluent. Carbonylation takes place at 195 °C (383 °F) and 415 psia. The reaction is exothermic, and the heat of reaction is removed in external heat exchangers E-102 (A and B) operating in parallel with circulating reactor contents and producing by-product steam at 185 °C (365 °F) and 150 psig.

The remaining gas after the reaction leaves the reactor at the reaction temperature. This gas contains significant amounts of methyl iodide, methyl acetate, acetic acid, water and methanol vapor. The gas stream is cooled to 5 °C (41 °F) in a sequential cooling process in E-103 (with cooling water) and E-

104 (with refrigerant). At this stage, the gas is completely dry and most of the valuable organic matter carried by it is condensed. The V-104 liquid separator removes the condensate from the gas and returns it to the reactor. The non-condensable gases CO, CO2, N2 and CH4 are sent to a washing column (C-101) to recover the remaining methyl iodide and methyl acetate.

The liquid exit stream from R-101 containing acetic acid, water, methyl iodide, methyl acetate, unconverted methanol, catalyst materials and small amounts of impurities such as propionic acid and acetaldehyde is cooled in heat exchange with the methanol stream entering the reactor. The cooled stream from E-101 is then flashed at 30 psia (pressure differential maintained through a control valve) in the V-101 flash drum to produce staem and liquid streams. Most of the acetic acid, unreacted methanol, methyl acetate, methyl iodide, water, propionic acid, and hydrogen iodide (another impurity in the reactor effluent, usually at the ppm level) are converted to the vapor phase during the flushing step and carried away. Along with incompressible methane, CO, CO2 and N2 gases, it enters the light cutting column, C-201. The non-volatile stream from the bottom of V-101 contains the catalytic material dissolved in the liquid stream. This flow returns to the reactor through the surge tank (V-102). A slip stream of high liquid flow passes through a cationic type, C-102A (or C-102B) ion exchange resin column to remove any corrosion products such as iron, chromium, etc. that may form in the process. Such corrosion products are harmful to the catalyst during carbonylation. The slip stream after the column joins the main recycle stream. The ion exchange column consists of a cationic ion exchange resin bed. The resin can be regenerated and only one column is working at a time.

A portion of the methanol feed is fed to the reactor as part of Stream 5 through the C-101 wash column where the methanol removes organics from the incompressible gases. Cleaned gases finally enter the gas flaring system. The methanol stream exiting the scrubber is pumped through V-103 to reactor R-101 as part of the recycle stream (stream 23).

- Section 200-Refining the product

The crude or crude acetic acid produced in Section 100 is fractionated in a series of three distillation columns (C-201 and C-203) to produce a high purity acetic acid product. V-201 and V-203 represent the respective reflux drums for the reference columns. Column condensers and reboilers are shown as E-201 through E-206 (odd numbers indicate condensers and even numbers indicate reboilers). Column C-204 (with reflux drum V-204, condenser E-209 and boiler E-210) is a scrubbing column and is primarily intended to remove

acetaldehyde from acetic acid. In the carbonylation of methanol with the type of catalytic system used in the process, no unsaturated substance is produced.

The overhead stream from C-201 (light-end column), which contains non-condensable gases, most of the water in the feed stream, and light organic compounds (methyl iodide, methyl acetate, and methanol) is partially contained in condenser E-201A. and B (connected in parallel) condenses. A significant amount of acetic acid is also used as overhead. Condensers operate at 50°C (122°F) and 30 psia. Under these operating conditions, most of the incompressible gases are removed from the column via V-201. The gas stream then passes through a chiller (E-211) where it is cooled to 2°C (about 36°F) by a refrigerant. The cooling step condenses the excess organic material in the gas stream. The V-205 Liquid Separator separates condensed organic matter from the non-condensable steam stream. The condensate is then recycled to R-101 through the V-103 mixing tank. V-205 gases in C-101 are scrubbed with methanol (stream 5) to remove residual methyl iodide and methyl acetate. The incompressible gas is finally sent to the fuel system to be used as fuel. The wash medium (methanol) is pumped from the bottom of C-101 through V-103 to reactor R-101.

The condensate in V-201 forms two distinct phases as it settles. The upper lighter aqueous phase contains water with some methanol, methyl acetate and acetic acid. The heavier organic phase is mainly methyl iodide, methyl acetate and acetic acid. The organic liquid is fed to C-204 where the associated acetaldehyde is removed from the overhead. The acetaldehyde stream, which also contains methyl iodide, is then sent to a waste treatment Section (not shown). The bottom of C-204 is mixed with a portion of the light phase material stream from V-201.

The upper light blue layer of V-201 is divided into two parts. Most of it is reflected to the C-201 column. The remainder is combined with the bottom end of C-204 and then the mixed stream (stream 11) is returned to reactor R-101 through mixing tank V-103.

A side stream containing hydrogen iodide, water, and acetic acid leaves C-201. Hydrogen iodide forms a high-boiling azeotrope with water and cannot be removed by conventional distillation. It dissolves more in the mixture of water and acetic acid than water or acetic acid alone. The lateral flow is drawn from the middle part of the column where the concentration of hydrogen iodide is maximum. Essentially all hydrogen iodide can be removed this way. The side stream (stream 25) is also returned to the reaction system via V-103.

The nearly dehydrated acetic acid is dehydrated from the bottom end of C-201 in the drying column C-202. The column operates at condenser conditions of

100°C (about 212°F) and 14.7 psia. The water obtained from the overhead is returned to the reactor through V-103. Part of the recycled water flow is cleaned to maintain the water balance in this process. This purified stream, which contains a small amount of acetic acid, is sent to the waste treatment Section for chemical treatment. Dehydrated acetic acid is finally processed in column C-203 refining where high purity acetic acid is obtained at the top of the column at 118°C (245°F) and 14.7 psia. Purified product, after cooling in E-207, is pumped to acetic acid holding tank T-201 and then to off-site tanks T-251A-D (not shown). A crude propionic acid stream containing a significant amount of acetic acid is obtained at the bottom of the column. This flow is directed to a holding tank (T-202) and after cooling in E-208 is stored in off-site tank T-252. Depending on the availability, this impure propionic acid may be used internally or otherwise marketed. Eventually, the current may shut down/burn out.

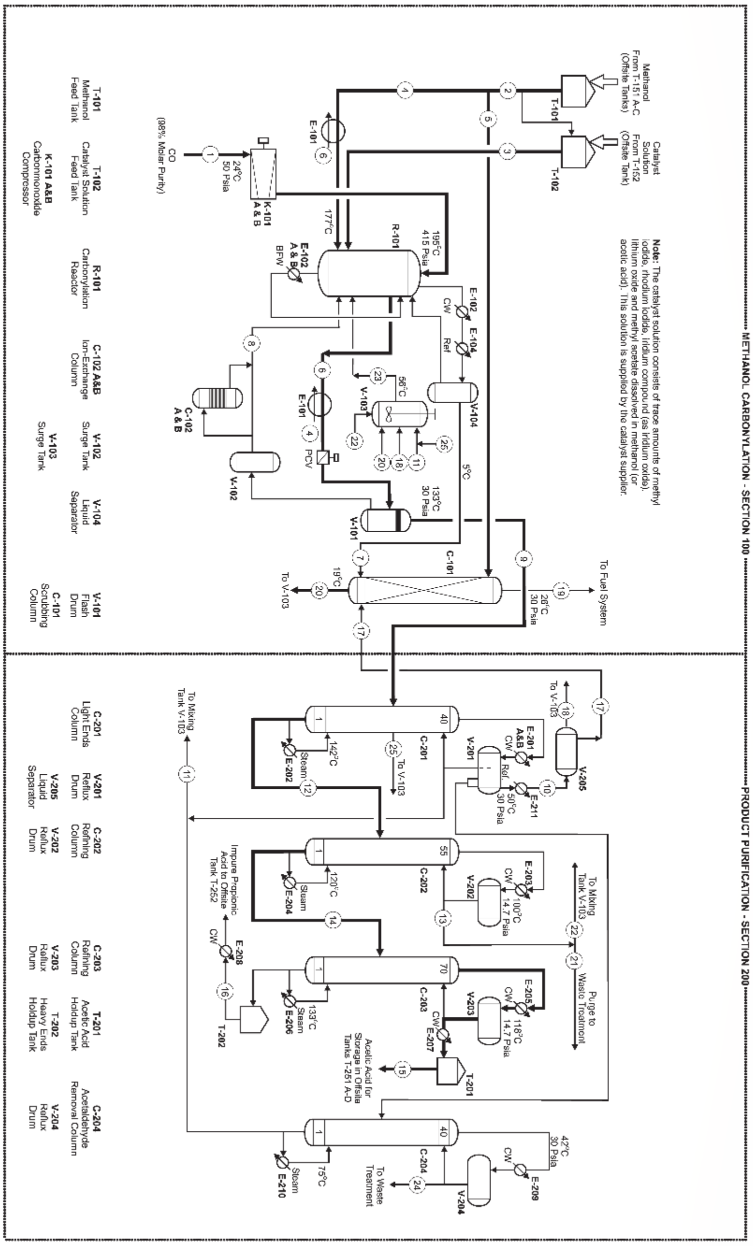


Figure 40- Process flow diagram of acetic acid production process by CELANESE method

3-4- Vinyl acetate monomer

Vinyl acetate monomer (VAM), an organic compound with the formula CH3COOCH=CH2, is a colorless liquid with a strong odor. VAM is a flammable liquid that does not mix with water but is slightly soluble. VAM is primarily used to produce polyvinyl acetate (PVAc) homopolymers and copolymers.

The plant of this process consists of three continuous Sections (Sections 100, 200 and 300). Section 100 is the oxyacetylation reaction Section. Uncondensed reaction products are sent to the gas recovery Section, Section 200, to remove VAM before steam recovery to the reaction stage. In Section 300, the liquid VAM is distilled to recover acetic acid for recycling and purification of the VAM product. The figure below shows the process flow diagram of this process and the table below shows the list of its main equipment.

• Section 100- oxyacetylation

Streams 1-3 are ethylene, acetic acid, and oxygen, respectively, the three power sources of the reactor. There are two main recycle streams that also enter the reactor:

- recycle gas stream 21 containing mainly ethylene and unreacted oxygen recovered from Section 200;

- Recycled acid stream 30, which mainly contains unreacted acetic acid and acetaldehyde produced from the hydrolysis of fraction 300.

The oxyacetylation reaction between ethylene, acetic acid and O2 is carried out in the vapor phase. The recycle gas from the gas recycle Section, which contains mainly ethylene, ethane, O2, and CO2, is enriched with fresh ethylene, stream 1, and fed to the C-101 gasifier. Stream 3, acetic acid, heated to approximately 238°F in E-101, also enters the evaporators where it flows to the bottom of the packer and is converted to gas. The recycled acetic acid from the recovery Section contains some polymeric materials as well as other heavy materials, which are removed using an E-102 film evaporator.

The gas is preheated from C-101 to 329 degrees Fahrenheit. Fresh oxygen, stream 2, is injected into the reactor feed, stream 4. The actual oxygen concentration will vary depending on the activity of the catalyst. The reactor feed enters at the bottom of the reactor and flows upward through the tubes filled with catalyst in the reactor. A small pressure drop occurs in the pipes. In the R-101 reactor, the gas phase reactants (ethylene, oxygen, and acetic acid) are partially converted to vinyl acetate and small amounts of byproducts. Reactors are large shell and tube heat exchangers. The catalyst in the tubes

consists of a silica base impregnated with Pd, Au and KOAc. The catalyst is recharged annually. The reaction temperature is 329°F and the pressure is 115 psia. The reactant feed contains a large amount of acetic acid, which acts as a diluent to prevent the formation of an explosive mixture and also to limit the formation of secondary CO2. Additional ethylene is also present to prevent explosive mixtures to control the feed flow rate through the catalyst tubes. Heat is removed by generating low pressure steam on the shell side of the reactor. Reactor temperature must be controlled to maintain yield to vinyl acetate. Excessive heat leads to tar and polymer deposition and catalyst destruction. If too much CO2 is converted, the large amount of heat released can also cause the catalyst to overheat.

Stream 5, the steam stream from the reactor outlet is cooled to 105°F, which condenses some of the reactor product into E-104. After cooling, the stream is sent to the separator vessel V-101. Stream 6 is a non-condensable steam stream containing mostly ethylene and CO2. The flow is sent to the K-101 compressor to the gas recovery Section. Stream 7 is the concentrated stream containing most of the acetic acid and VAM is sent to the product recovery Section.

• Section 200 - Recovery of GAS

CO2 removal steps can be any of several commercially available CO2 removal processes. The purpose of the CO2 absorber is to remove CO2 from the recycle gas stream to the reactor. This is done using a carbonate absorption process. The CO2 produced is converted to potassium bicarbonate, which is then regenerated to potassium carbonate in a CO2 strip. The bottom stream of the CO2 absorber is sent to the CO2 strip to regenerate the rich carbonate content of the CO2 absorber bottoms from the CO2 absorber reactor by removing the CO2. Potassium bicarbonate is divided into potassium carbonate by discharging CO2 and water, which goes from the top of the CO2 stripper to the flare. The bottom stream of lean carbonate is returned from the stripper to the top of the CO2 absorber. The recycle feed to the CO2 absorber is from the scrubber overhead stream.

According to the process flow diagram of this process, stream 6, the depressurized gas from the reaction Section, is cooled to 40°F with acetic acid, stream 9 from the 300 Section. All VAM in the gas stream is effectively absorbed by acetic acid. The gas stream from the VAM absorber, C-201, is scrubbed in water scrubber C-202 with stream 10 and then carbonate scrubber C-203. The carbonate stream from C-203 is separated from the absorbed CO2 using pressure and heat in the CO2 strips, C-204.

The gas from the stripping operation, mainly CO2, is sent through the vent condensers, E-206, and vented to the atmosphere as stream 18. Compensation carbonate is fed from T-201A-D to C-203. The gas stream from the C-203 carbonate scrubber is recycled to the reaction Section. Stream 19 is heated in a cross-flow heat exchanger where it cools the reactor product gas, stream 5. A purge stream, stream 20, is taken to prevent ethane from forming in the system. The purge gas stream is treated in a thermal oxidizer. The resulting stream 21 is recycled to the R-101 reactor.

• Section 300 - Product recovery

VAM is recovered and purified in a series of distillation columns. Steam 7, the condensate separated from the reactor product outlet, and stream 11, the VAM/acetic acid solution from the gas recovery Section are both fed to the C-301 acetic acid recovery column. A small amount of inhibitor is added to the top of the columns to inhibit the polymerization of VAM.

The overhead stream is VAM and H2O, which forms an azeotrope and exits the top of the column. This flow is sent to a container where the flow is sent to the Decanter V-301 at the bottom.

The aqueous layer, stream 16, is sent from the bottom to the C-302 water strippers. The organic stream produced from the decanter devices associated with the strips is fed to the C-303 crude VAM columns. The aqueous stream obtained from C-301 is sent to a water stripper, C-305, before the effluent treatment facility.

The organic layer is removed from the top. A portion of this stream is recycled to the columns and the balance, stream 26, is sent to the purified VAM column, C-302.

Stream 24, acetic acid is cooled from the bottom of the acetic acid recovery columns in a converter. A portion of the recovered acetic acid, stream 9, is sent to the absorber in Section 200. The remainder, stream 22, is recycled to the reaction Section. C-302 crude VAM columns separate acetaldehyde from the product and are also used to complete VAM drying. Acetaldehyde is formed as a result of hydrolysis of VAM. Vinyl acetate is hydrolyzed and forms acetaldehyde and acetic acid during distillation. A small amount of inhibitor is added to the top of the columns. The distillate from C-302 condenses to form two layers that are decanted into V-305. The bottom blue layer is sent to Strippers H2O C-305. Stream 33 is a byproduct stream where ethyl acetate is removed at C-306.

Stream 28, a portion of the organic layer was distilled in C-303 acetaldehyde columns. Stream 29, the bottom stream from the acetaldehyde columns is

recycled to the crude VAM columns. Stream 23, overhead from C-303, which contains most of the acetaldehyde formed, is recycled to the reaction Section, where it is finally oxidized to acetic acid.

Stream 31, the bottom of the crude VAM columns is essentially free of acetaldehyde and H2O, but still contains some acetic acid and other heavies. It is fed from C-304 purified VAM columns. The bottom stream, which contains acetic acid and VAM, is recycled to C-301. Stream 32 is the top product of C-304 VAM with a purity of 99.9% and a maximum acidity of 0.007% by weight as acetic acid.

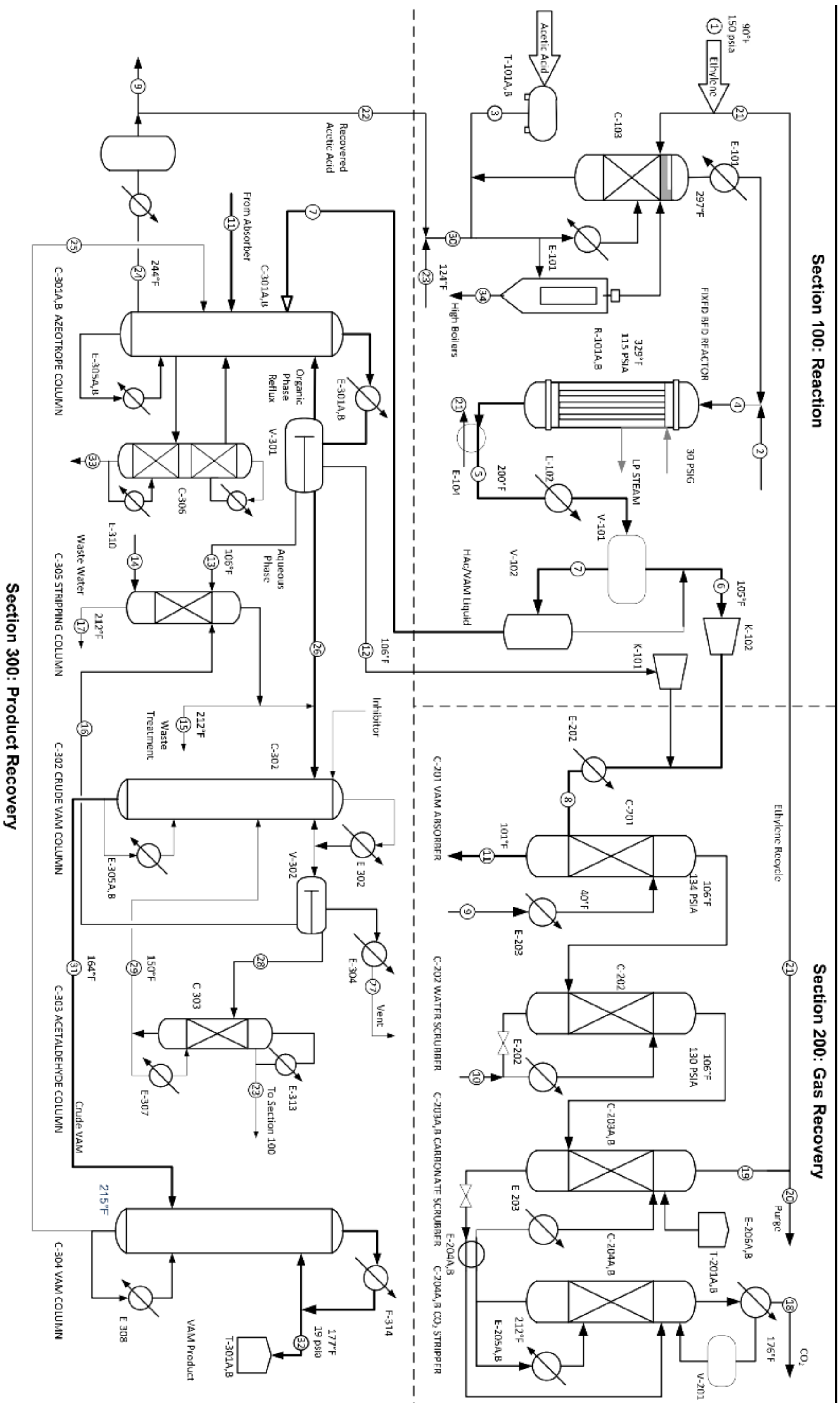


Figure 41- Process flow diagram of the VAM production

3-5- Polyvinyl alcohol (PVOH)

The starting material for the production of polyvinyl alcohol (PVAL) is not vinyl alcohol monomer, which exists as tomeric acetaldehyde (tomeric ratio CHa=CHOH:CH,CHO = 1:30000), but polyvinyl acetate, which is hydrolyzed to PVAL. The term "hydrolysis" is somewhat misleading in this context because polyvinyl acetate does not readily react in the presence of water to give PVAL. Polyvinyl alcohol was first prepared by Hermannn, Haehnel and Berg in 1932 by an ester exchange reaction. A large industrial enterprise for the production of fibers, especially in Japan, was established after the breakthrough in 1938 by Sakurada, Yazawa, and Tomanasi in the preparation of water-resistant stabilized fibers. Since then, many other applications have been developed, such as web sizing, coatings, adhesives, and extruded products.

The selected process in this report is vinyl acetate polymerization. The conditions of polymerization of vinyl acetate and hydrolysis of polyvinyl acetate are mentioned below:

	First Stage	Second Stage
Reaction temperature °C	60 (140°F)	60 (140°F)
Reaction time (hr)	1.5	1.5
Conversion (based on VAM charged) (%)	30	55
Type of operation	Continuous	Continuous

An overall yield of 1.983 pounds of vinyl acetate per pound of PVAL product is assumed. The present process is shown in the figure below and is divided into five sections, Section (100) raw material storage and purification, (200) polymerization and hydrolysis, (300) solvent separation and product drying, (400) transport and bulk transport, and (500) solvent and byproduct recovery. The main equipment is listed in the table below.

- Raw material storage and treatment Section

The inhibitor in the vinyl acetate monomer is removed in a stripping column, C-101, and the pure uninhibited VAM is stored in a day tank, T-101. The initiator solution is prepared in a make-up tank V-102 by mixing methanol with azobisisobutyronityl. This solution along with VAM is charged to the polymerization part by charging pumps.

- Polymerization and hydrolysis Section

Vinyl acetate polymerization is done at 140 degrees Fahrenheit (60 degrees Celsius) in two stages with an average polymerization rate of 20% conversion per hour in the first stage and 16.7% per hour in the second stage. The first stage reactor, R-201, is equipped with a turbine stirrer for thorough mixing of the initiator solution and VAM, while the second stage reactor, R-202, is equipped with a paddle stirrer for the viscous polymer solution. The reaction temperature in both reactors is controlled by reflux condenser and cooling jacket.

The polymer solution from the second reactor, R-202, is collected in a polymer solution surge tank, V-202. Also, an inhibitor called hydroquinone methyl ether has been added to the surge tank, which prevents any polymerization in the C-201 monomer stripping column. Evaporation of methanol from the evaporator, E-204, is used to separate the unconverted monomer in the polymer solution. Additional liquid methanol is also added to the stripping column to control the viscosity of the polymer solution, C-201. Essentially all of the VAM is removed from the top of the column as a methanol solution and recycled to the R-201 reactor. The polymer product from the bottom of the monomer stripping column is a 35% by weight solution of PVAC in methanol.

This solution is continuously hydrolyzed in two R-204 hydrolysis reactors A and B in parallel. The reaction is catalyzed by sodium hydroxide-methanol solution, which is continuously charged every 5 minutes from the V-207 feed tank according to Kuraray's patent. The solution is prepared at each turn in a compensation tank, V-206. The PVAL slurry continuously discharged from the hydrolysis reactors is collected in a surge tank V-208 and neutralized with acetic acid from the acetic acid storage tank, T-551. Also, in this section, an off-spec tank V-251 is installed to store PVAC with off-spec conditions, which is later sent for disposal or to the polymer solution surge tank V-202.

- Solvent separation and product drying Section

The neutralized PVAL slurry is sent to a centrifuge S-301, where the PVAL is separated from the original solution and washed with methanol from the methanol storage tank, T-502. The stock solution and methanol wash from the centrifuge are collected in a crude solvent storage tank, T-301. The washed PVAL containing 10% by weight of methanol was dried in a PAC-301 rotary dryer. Closed-loop nitrogen gas is used to dry the PVAL, and part of the methanol in the drying nitrogen is condensed from the dryer in the condenser E-301 and separated from the condensed methanol tank T-301.

- Bulk transportation Section

The dried PVAL from the rotary dryer PAC-301 is collected in the product collector PAC-302 and after passing through the product screen PAC-401 is transferred to the storage bins PAC-402 to PAC-405. These storage bins have a total production capacity of 15 days. PVAL product is loaded from storage bins into rail cars or trucks for sale.

- Solvent recovery Section and by-products

The crude solvent from the storage tank, T-301, contains methanol, ethyl acetate, some sodium acetate, and water. Methanol and methyl acetate are recovered as overheads from the mixed solvent column C-501 and transferred to an ester hydrolyzer C-502, where the methyl acetate is hydrolyzed to methanol and acetic acid. The top of the hydrolysis column is packed with porous polyethylene fillers containing a cation exchanger to catalyze the hydrolysis reaction. The lower part of the column is packed with Raschig rings and is used as a separation zone to remove any methyl acetate from the descending liquid. A stream of water is added near the top of the column for the hydrolysis reaction and for increasing steam density. Any steam passing through the column is condensed in a total reflux condenser, E-503, mounted on top of the column. Essentially all of the methyl acetate is hydrolyzed, and the stream leaving the bottom of the column consists of methanol, acetic acid, and water. The methanol is separated from the acetic acid and water in a C-503 methanol column and collected in the methanol storage tank, T-502, before being recycled to the process. The dilute acetic acid from the bottom of the methanol column is stored in the crude acetic acid tank, T-503.

Aqueous sodium acetate from the bottom of the mixed solvent column, C-501, is reacted with sulfuric acid in reactor R-501 to convert sodium acetate to acetic acid. The reaction product is combined with dilute acetic acid from the column, C-503, in the crude acetic acid tank, T-503. From this tank, crude acetic acid is extracted with ethyl acetate in a C-506 rotating disc contactor to recover acetic acid. In an acetic acid recovery column, C-507, acetic acid is separated from ethyl acetate and collected in acetic acid storage tank, T-504. Part of acetic acid is used to neutralize the hydrolysis reaction product. The remainder is sent to the VAM plant or sold as a by-product.

The sodium sulfate solution from the contactor, C-506, contains ethyl acetate and is combined with the dilute ethyl acetate solution from the lower layer of the phase separator, V-504, to recover the ethyl acetate in the ethyl acetate recovery column, C-508. The recovered ethyl acetate is combined with the ethyl acetate from the upper layer of the phase separator and used in the C-506 column to extract acetic acid. The bottom stream from the ethyl acetate recovery column, C-508, is sent to wastewater treatment.

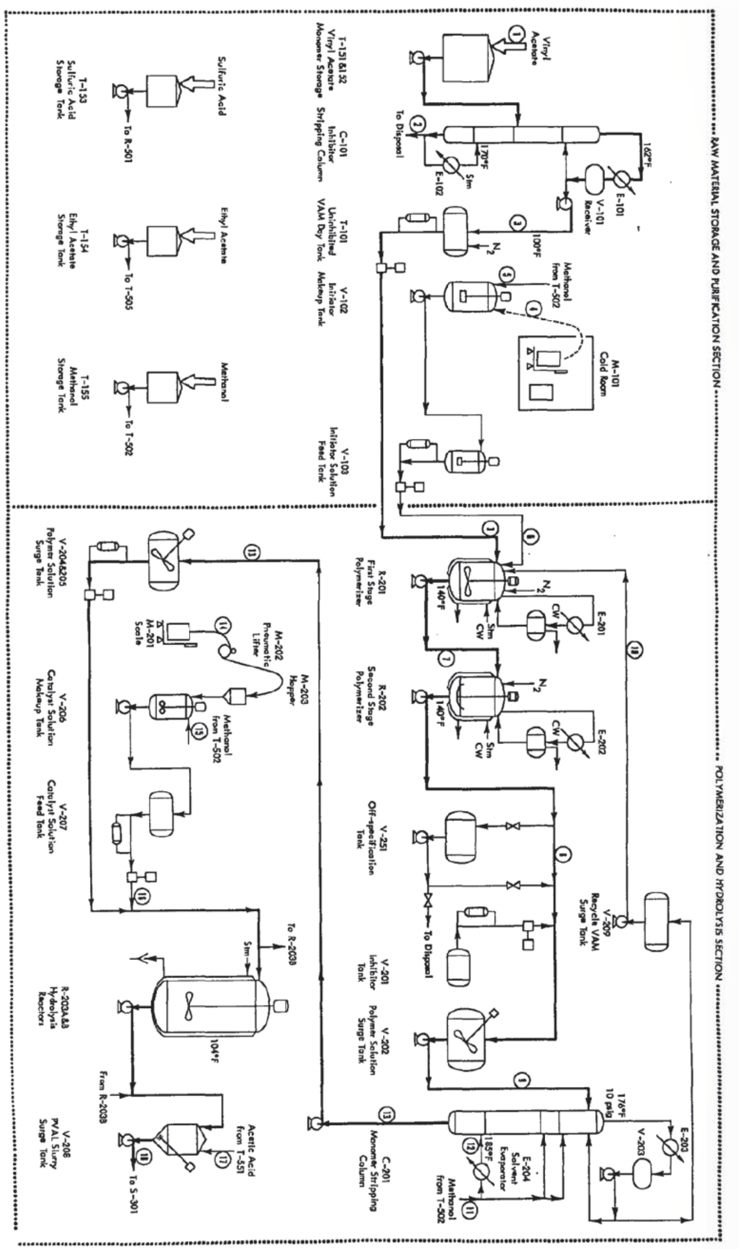


Figure 42- Process flow diagram of the PVAL production

3-6- Methylamines

Leonard's method is selected according to the consultant's reviews. The process flow diagram of the production process of methylamines is shown in the figure below and the list of its main equipment is given in the table below.

A liquid feed of methanol and ammonia is mixed with a liquid return stream and then heated and vaporized in the HE-1201 to 750ºF. Then the steam stream passes through the F-1201 furnace and is heated to 842ºF. This superheated stream is the feed to the R-1201 reactor, which contains 5 packed beds of catalyst. The reactor raw product vapors are recirculated through HE-1201. So that with partial cooling and condensation, most of the sensible heat and heat of reaction are recovered and transferred to the feed stream. Then the product stream in HE-1202 is fully condensed and sent to the V-1202 pressure vessel.

From the crude product discharge tank, the liquid goes to the HE-1203 preheater where it is partially evaporated, then enters the ammonia separator. where the operating pressure is 380 psia and the feed tray temperature is 145ºF. In this part, the total ammonia is separated at the top of the column in the form of an azeotrope with trimethylamine (94 mol% NH_3 + 6 mol% TMA). This azeotrope is condensed with cooling water and returned to the beginning of the process. The uncondensed material, mostly CO and H_2, is washed with water in a C-1205 tower to remove residual ammonia. The dissolved amines at the bottom of the tower go to the C-1202 extractive distillation tower, which operates at 90 psia. Water is added above the feed so that the composition under the water feed tray is 65% by weight of water. Trimethylamine is separated above the water feed with a purity of at least 99.3%.

The bottom product goes to the C-1203 dehydration tower. In this tower, mono and dimethylamine are distilled at the top of the column at 120 psia. The water at the bottom of the tower passes through the HE-1203 preheater, where the sensible heat of the water is transferred to the raw feed product. In this part, the number of moles of water is equal to the number of moles of methanol consumed and emptied into the waste stream, while the remainder is cooled to 125 and returned to the extractive distillation.

The liquid products of mono and dimethylamine are separated in the fourth tower. Meno is distilled at 145 degrees at the top of the tower while Di is at the bottom. Both final products have a purity of 99.3%. All these products can be returned to the beginning of the process to prevent the formation of unwanted products.

Products under pressure are stored in spherical tanks T1203, T1204, T1205.

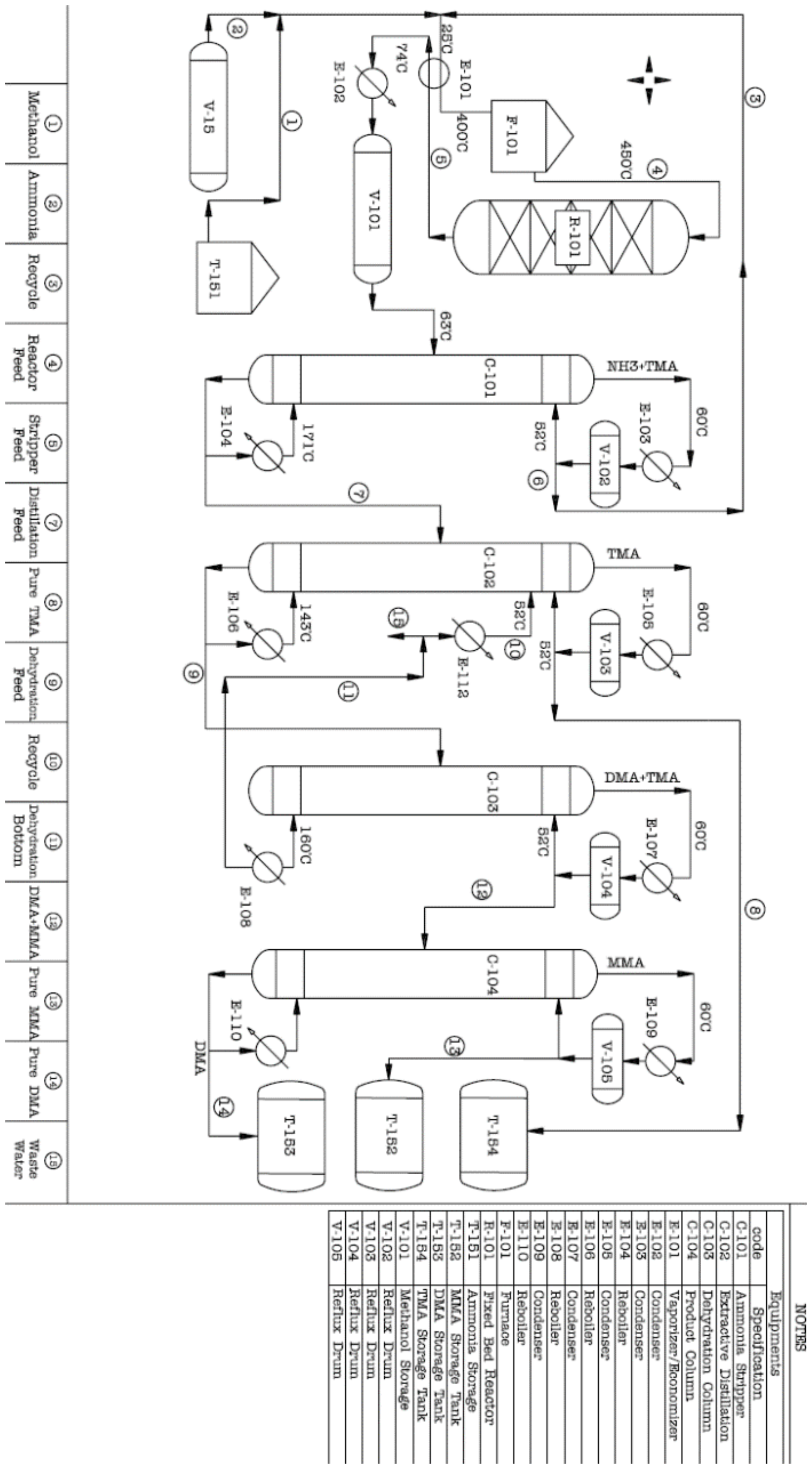


Figure 43- Production process of methylamines by Leonard's method

3-7- polyacetal (POM)

Acetal resin compounds (which are usually also called polyacetal or polyoxymethylene) usually include compounds based on formaldehyde homopolymers whose end groups are closed by esterification or etherification. Also, formaldehyde copolymers or cyclic oligomers of formaldehyde (trioxane) and other monomers that produce oxyalkylene groups with at least two adjacent carbon atoms in the main chain. The end groups of their copolymers can be hydroxyl terminated or thermally stabilized. The proportion of comonomers can be up to 20% by weight.

The figure below shows the process flow diagram of the polyester homopolymer production process and the table below shows the list of its main equipment.

- Production of formaldehyde (section 100)

Formaldehyde is synthesized by passing methanol steam and excess air through R-101 tubular reactor, containing molybdenum and iron oxides catalyst, at a temperature of 250 to 450 degrees Celsius (Formex process). The methanol content in the methanol-air mixture is below the explosive limit of 7-8 percent by volume and the conversion percentage is between 95 and 98 percent.

The gases leaving the reactor are cooled by the incoming feed streams and then transferred to the first of three countercurrent absorption columns C-103 to C-105. Here, formaldehyde vapors are separated from the reaction gases by forming a complex with cyclohexanol:

Formaldehyde is absorbed by cyclohexanol in the first two columns (C-103 and C-104) in series, and traces of formaldehyde and cyclohexanol vapors are absorbed by water in the third tower, C-105. Then the unabsorbed gases are released into the atmosphere.

The bottom products of the absorption towers containing cyclohexanol, cyclohexyl hemiformal, water, methanol, and other impurities are distilled at C-106 to separate water as the cyclohexanol azeotrope (80 wt% water and 20 wt% cyclohexanol at 203°F and 760 mmHg pressure). to be

The end of the cyclohexyl hemiformal passes from the azeotrope column to a C-107 decomposition column at 320°F, where anhydrous formaldehyde is liberated at 99.5% purity. Cyclohexanol is then cooled and recycled to C-103 to C-106 absorption and distillation columns. Formaldehyde gas is cooled in alternating cold condensers, which remove traces of cyclohexanol and water along with some low molecular weight polymers of formaldehyde. The

polymerizate is periodically removed from the condenser by blowing with hot nitrogen with a gas mixture that is recycled to the primary absorber or used to produce an aqueous solution of formaldehyde.

- Formaldehyde polymerization (Section 200)

Formaldehyde polymerization is done using the anhydrous solution suspension method. Anhydrous formaldehyde gas at 100°F and 2 psig is introduced to the top of the R-201 polymerization reactor. Cyclohexane, at 750°F and containing a small amount of tri-N-butylamine initiator, enters the reactor shell tangentially. This provides a large, rapidly changing liquid surface where formaldehyde polymerizes to form finely divided high molecular weight POM. To ensure good removal of polymerization heat, the solid content in the polymerization reactor is limited to a maximum of 20%.

The polymerization medium is cooled by flash evaporation of part of the cyclohexane at 920°F and 95 mmHg to 740°F in E-201. Also, a portion of the reaction medium is continuously withdrawn, filtered, and washed in the S-201 rotary vacuum filter to separate polymer solids, which are transferred to the R-301A end-group acetylation reactors via E. The filter, along with flash condensate and make-up cyclohexane, is then recycled to the polymerization reactor.

- Stabilizing the end of the chain (Section 300)

Polymeric solids containing some cyclohexane are continuously acetylated at 280-285°F with acetic anhydride containing some sodium acetate catalyst in acetylation reactors R-301A through E. After acetylation, the acetic anhydride-polymer slurry is cooled and filtered through an S-301 rotary vacuum filter to remove chain-end stabilized polymer solids. This filtrate is distilled in a C-301 cyclohexane partition column to recover the cyclohexane for recycling to the formaldehyde polymerization section. And the bottom 25% of cyclohexane is further distilled in a C-302 column with overhead boilers to distill the methylene diacetate, deoxymethylene diacetate, and low molecular weight POM diacetate that would otherwise be generated in the acetylation system.

- Final ending (Section 400)

The acetylated solids are redissolved in acetone, centrifuged and washed to remove acetic anhydride and catalyst from the polymer solids. Then these three steps are repeated. The acetone wash is fractionally distilled in the C-402A&B column to remove the acetone overhead. The bottom products are further separated in column C-401 to separate acetic acid from acetic anhydride. The polymer is slurried a third time—this time in water—and then centrifuged and washed to remove as much of the previous acetone as

possible, as well as any remaining water-soluble catalyst. They are finally dried by compression rolls (S-404) and rotary tube dryer (E-409). The washings are fractionally distilled in a C-403 column to recover the acetone and then discarded.

Dry polymer solids are extruded (M-406) and cut into one-eighth inch diameter pellets. Antioxidant, stabilizer and other additives are added before extrusion or in the polymer mixer. Air conveyors take polymer pellets to various tanks, sampling and storage, and to hoppers for packaging or bulk shipping. The resin is typically packaged in 50-pound polybags with aluminum foil liners and polyethylene liners.

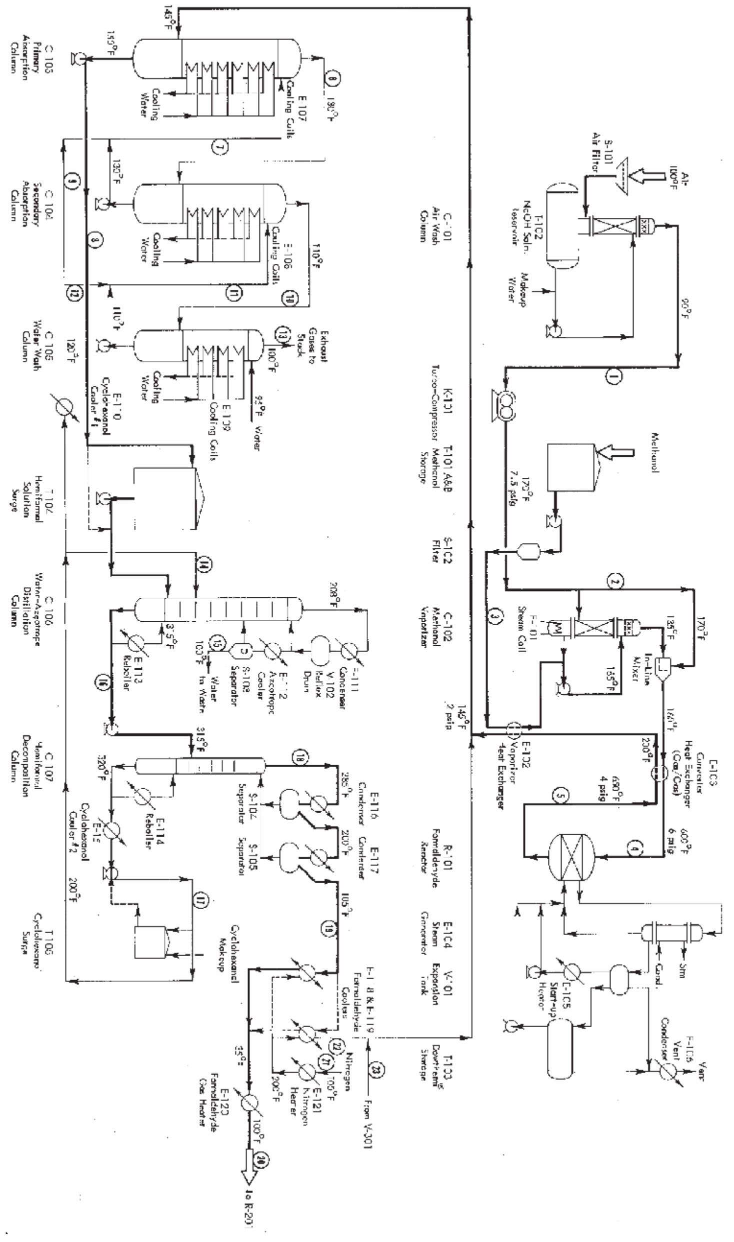


Figure 44- Process flow diagram of polyester homopolymer production

3-8- Formaldehyde

3-8-1- SILVER CATALYST PROCESS Complete Conversion without Methanol Recycle

At a temperature of around 700 °C, methanol conversion is sufficiently high to eliminate the final distillation column. A complete conversion process is shown in Figure 3.3. The plant is similar to that described in the previous section. Most new plants that employ the silver catalyst process are based on this type of design.

A mixture of methanol and water (typically in a 65:35 ratio) is fed to the evaporator and evaporated by a stream of filtered air at 65 to 70 °C. The composition of the gas mixture is in the non-explosive range, with the quantity of air maintained outside the upper explosive limit of 36.5 percent methanol in air. Flammability is further suppressed by the presence of water in the mixture. A gas superheater raises the temperature to 90 °C and the mixture passes through a flame trap to the reactor.

In the reactor, formaldehyde is produced by an oxidative dehydrogenation reaction of methanol. After reaction on the silver catalyst, the gases are rapidly cooled in order to raise steam and preheat the methanol-water feed. The reaction gas enters the packed absorption column where condensation and absorption take place in two or more stages with indirect cooling on the recirculation loops. The gas is scrubbed with fresh cooled process water before leaving the absorber. This off-gas can be incinerated, if required for environmental or economic reasons; the heat value from hydrogen and other components permits the generation of steam.

A number of variations are possible. For example, the process operated by BASF includes a recycle of either part of the off-gas or of a mid-column formaldehyde solution as additional inert components to adjust the reactor feed composition. The composition of the final formaldehyde product determines which, if any, of the recycle streams is used. Heat from the absorber coolers can also be used to provide a contribution to the evaporation load.

It is claimed that the product from the absorber can contain up to 55 percent formaldehyde. A methanol content of between 1.5 and 5 percent in 37 percent formaldehyde solution is typical of the various commercial processes. Formic acid concentrations of 0.01 to 0.02 percent are typical. This process is well suited for the production of commercial grade (37 percent) formaldehyde with allowable methanol concentrations between three and five percent. At this level, methanol assists in inhibiting formaldehyde polymerization.

Because of the lack of a final methanol column, the capital costs of the total conversion process are lower than that using incomplete conversion and recycle. It also has a lower energy requirement, with a net steam credit typical for both the production process and off-gas incineration. The overall process yield ranges from 85 to 92 percent and is typically 90 percent.

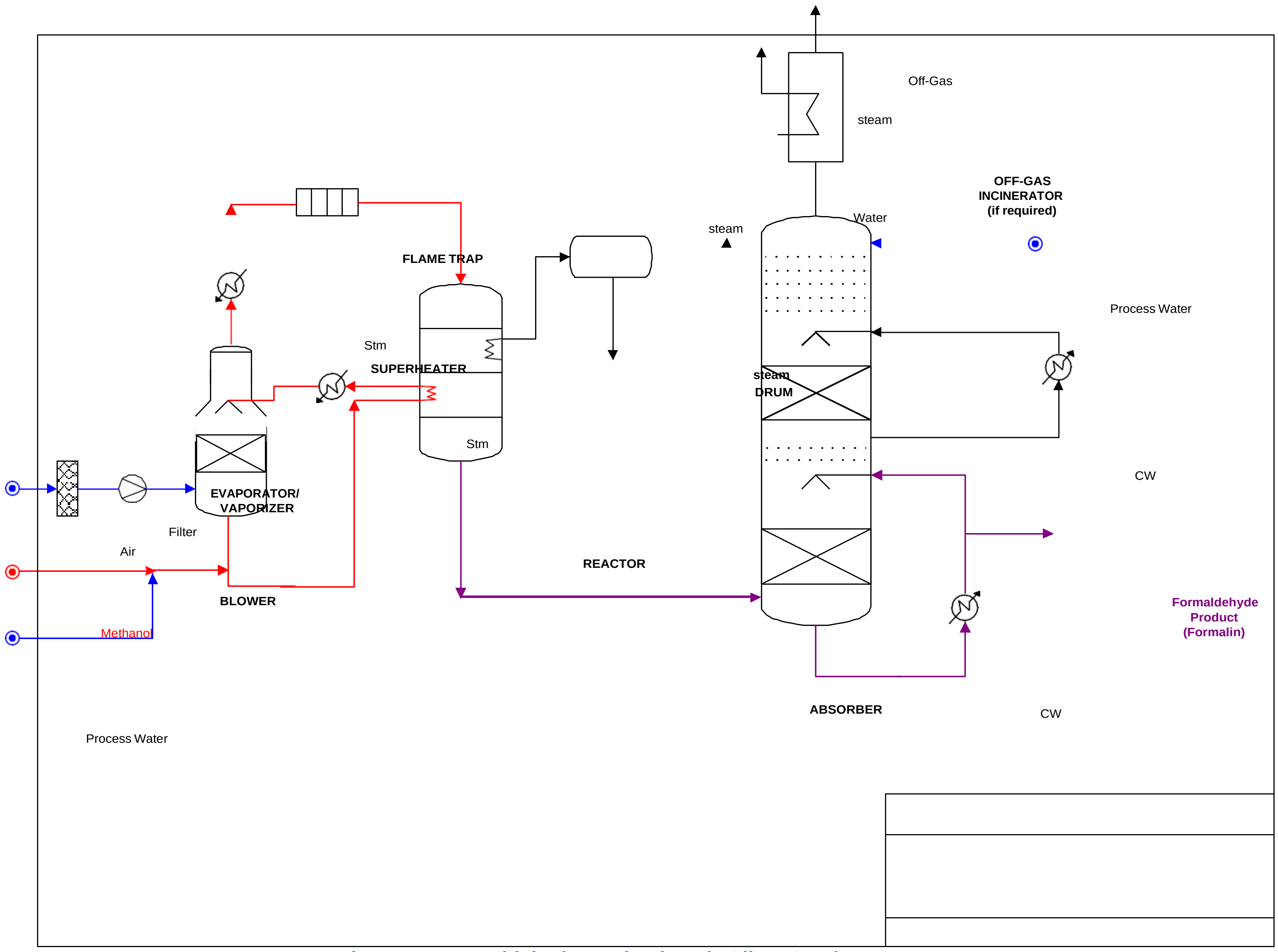


Figure 45- Formaldehyde Production via Silver Catalyst

3-9- UREA-FORMALDEHYDE RESINS

3-9-1- Introduction

Urea-formaldehyde (UF) and melamine-formaldehyde (MF) resins are the most common amino resins. They are produced by adding formaldehyde to urea or melamine to form methylol monomer units, and subsequent condensation of these units to form a polymer. The process technology to produce UF and MF resins is very similar and both resins can be made on the same equipment. It is also common to use melamine for reinforcing UF resins. Depending on the content of melamine, they are abbreviated as UMF (less than 10 percent melamine) and MUF (more than 10 percent melamine) resins. However, these resinsare not covered in this report.

3-9-2- Process Description

The production process for urea-formaldehyde (UF) resins can be represented as two steps, as mentioned above. The first step is hydroxymethylation, achieved by reacting formaldehyde and urea in alkaline or mildly acidic conditions. The formaldehyde used in UF resin production is usually supplied as an aqueous solution, but in special cases, paraformaldehyde is used. The formaldehyde production plant may also produce an aqueous solution of urea-formaldehyde precondensates, which can be a feed to the UF resin plant. The second step is condensation of the intermediate components, leading to the formation of chainsranging from dimers to fully cross-linked networks. Condensation is catalyzed by acids and the reaction isstopped at a suitable degree of polymerization by lowering the temperature and raising the pH. For aqueous solutions or suspensions, sufficient polymerization is required to give a long shelf life while maintaining ease of handling. Condensation of the resins to give substantial cross-linking is part of the curing processas the resin is applied. Production processes are typically designed for batches of five to 60 m^3. A typicalbatch cycle time is eight hours.

The product may be supplied to the point of use in a number of forms including aqueous solutions, resin powder, and filled molding compounds. In pure UF resins, the ratio of formaldehyde to urea can be varied. The adhesive properties and reactivity increase with higher formaldehyde content, but at the expense of greater atmospheric release of formaldehyde. UF resins are more prone to formaldehyde emissions than other formaldehyde-based resins. Other UF products are mixed amino resin condensates and resins modified by alcohols or other compounds to give specific properties.

Besides modification of the resin, other important factors for the resin preparation are the degree of polymerization and the intensity of the

crosslinking. A high degree of polymerization results in a solid polymer, whereas a low degree of polymerization results in a syrup that can be used as an adhesive or laminating resin. The syrup can also be combined with fillers for the manufacture of molding compounds or used in coating formulations. For storage and transportation purposes, the syrup can be spray dried to form a powder.

A simplified process flow sheet is shown in Figure 4.3. The UF resin reactor is designed to produce a liquid resin with a solids content of approximately 50 to 55 weight percent. The liquid resin is typically processed downstream in spray dryers to form a resin powder. The process shown is a batch process carried out in stainless steel reactors that are equipped with an agitator to ensure good mixing, internal coils for heating and cooling of the batch, and a reflux condenser. Depending on the plant capacity, multiple reactors can be used; two are shown in the flow sheet.

Formaldehyde solution is charged to the reactor by means of a pump from a storage tank, which is fed either directly through a pipeline from an on-site formaldehyde plant or by tank car. Uninhibited (no methanol added for stabilization) formalin (37 weight percent formaldehyde) is typically used. Urea prills are charged directly into the reactor by means of a conveyor system from the urea storage area. (Fertilizer grade urea should be avoided.) Chemicals used as catalyst and/or for the adjustment of the pH of the batch are charged into the reactor from charging tanks.

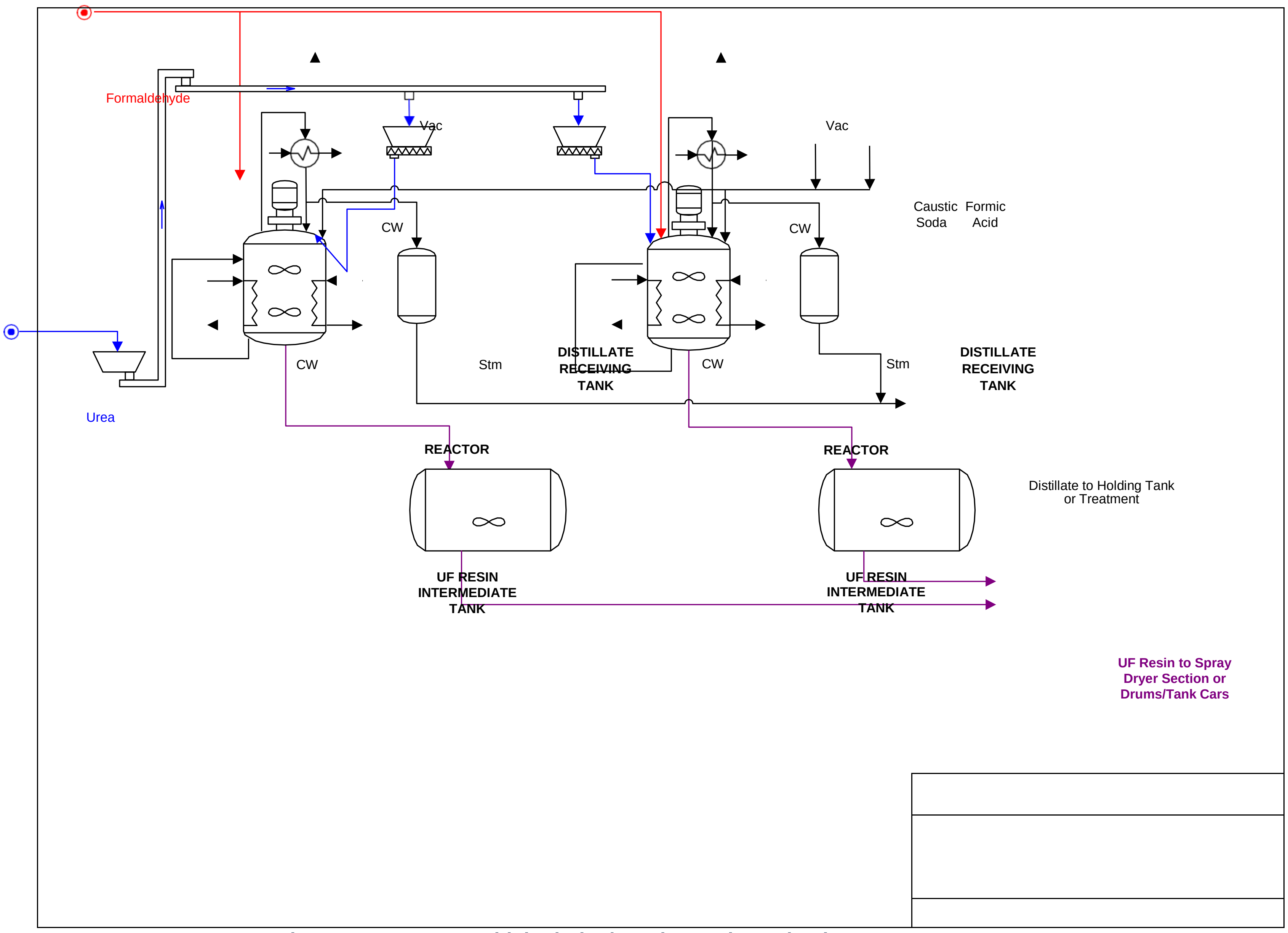


Figure 46- Urea-Formaldehyde (UF) Resin Batch Production Process

3-10- MELAMINE-FORMALDEHYDE RESINS

3-10-1- Introduction

Urea-formaldehyde (UF) and melamine-formaldehyde (MF) resins are the most common amino resins. They are produced by adding formaldehyde to urea or melamine to form methylol monomer units, and subsequent condensation of these units to form a polymer. The process technology to produce MF and UF resins (together called amino resins) is very similar and both resins can be made on the same equipment.

3-10-2- Process Description

The production process for melamine-formaldehyde (MF) resins can be represented as two steps. The first is hydroxymethylation, achieved by reacting formaldehyde and melamine in mildly acidic or alkaline conditions. The formaldehyde used in MF resin production is usually supplied as an aqueous solution, but in special cases, paraformaldehyde is used. The second step is condensation of the intermediate components, leading to the formation of chains ranging from dimers to fully cross-linked networks. Condensation is catalyzed by acids and the reaction is stopped at a suitable degree of polymerization by lowering the temperature and raising the pH. For aqueous solutions or suspensions, sufficient polymerization is required to give a longer shelf life while maintaining ease of handling. Condensation of the resins to give substantial cross-linking is part of the curing process as the resin is applied. Production processes are typically designed for batches of five to 20 m^3. A typical batch cycle time is six hours.

The product may be supplied to the point of use in a number of forms including aqueous solutions, resin powder, and filled molding compounds. MF resins can be hardened by the application of heat or, at ambient temperature, with acidic catalysts. As with UF resins, modified melamine resins can be produced. Alcohol- modified resins are used in surface coatings and textile finishing, while sulfate-modified MF resins can be employed in concrete liquefiers.

Besides modification of the resin, another important factor is the degree of polymerization. A high degree of polymerization results in a solid polymer, whereas a low degree of polymerization results in a syrup that can be used as an adhesive or laminating resin. The syrup can also be combined with fillers for the manufacture of molding compounds or used in coating formulations. For storage and transportation purposes, the syrup can be spray dried to form a powder.

A simplified process flow sheet is shown in Figure 4.4. The MF resin reactor is designed to produce a liquid resin with a solids content of approximately 50 to 55 weight percent. The liquid resin is typically processed downstream in spray dryers to form a resin powder. The process shown is a batch process carried out in stainless steel reactors that are equipped with an agitator to ensure good mixing, internal coils for heating and cooling of the batch, and a reflux condenser. Depending on the plant capacity, multiple reactors can be used; two are shown in the flow sheet.

Formaldehyde solution is charged to the reactor by means of a pump from a storage tank, which is fed either directly through a pipeline from an on-site formaldehyde plant or by tank car. Uninhibited (no methanol added for stabilization) formalin (37 weight percent formaldehyde) is typically used. Melamine is charged directly into the reactor by means of a conveyor system from the melamine storage area. Chemicals used as catalyst and/or for the adjustment of the pH of the batch are charged into the reactor from charging tanks.

The solids content of the liquid resin is controlled by the operating conditions (such as pressure) and the specifications of raw materials used in the reaction. For example, at atmospheric conditions, the production of 50 to 55 weight percent liquid resin can be made, but the use of vacuum evaporation facilities would allow higher solids content resins to be produced, although this is not very common in the production of MF resins. The batch conditions are controlled by the addition of caustic soda and formic acid (or other organic or mineral acid) to adjust and control the pH. The main reaction between formaldehyde and melamine is carried out under alkaline conditions. The heating of the reactor is accomplished by using low pressure steam and the cooling by cooling water from a closed circuit cooling tower system or cooling water of suitable temperature from another source. In the final cooling stage of the resin, in intermediate or storage tanks for longer periods, chilled water may be required.

The reactor typically has a circulation system for sampling and monitoring of the processed resin during the process sequence. The progress of the condensation reaction is monitored by measuring the viscosity or the water solubility of the MF resin. Once the desired level is reached, the reactor is cooled to stop the reaction. For discharging the resin from the reactor, a strainer, discharge pump, and filter are provided for each reactor. A computer-based control system is typically used to monitor raw material charging and the temperature profile of the batch.

Liquid MF resins are not stable; the viscosity tends to increase and the pH changes during extended storage periods. To ensure the longest possible storage time and optimal quality, the resin should be stored in agitated tanks

with a temperature preferably between 25 and 30 °C.

For the production of MF resin powder, the liquid MF resin is fed to a spray dryer section. The spray drying operation can be a continuous process, so an intermediate holding tank is used as a buffer with the liquid resin batch process. The liquid resin is pumped from the intermediate holding tank to an atomization system. The temperature of the liquid resin is adjusted to ensure the correct viscosity for atomization. The feed is sprayed into the spray dryer at a controlled rate through a rotary disc atomizer. The atomized particles are dried to the desired moisture level by co-current hot air flow. Fresh ambient air is filtered and heated for the drying process. The air is contacted with the atomized resin spray in the drying chamber. The temperature of the drying air will vary depending on the type and quality of the resin to be produced. Temperatures can range from 150 to 250 °C.

The MF powder is pneumatically discharged from the bottom of the drying chamber and separated from the air in cyclone separators and a reverse pulse bag filter. The powder is then conveyed by dried air pneumatic conveyors to powder intermediate storage bins to await bagging. MF resin powders are extremely stable and the storage life allows for deep-sea transportation. To ensure the longest possible storage time and optimal resin quality, the resin should be stored in a dry storage space, away from heat and sunshine, at temperatures below 40 °C.

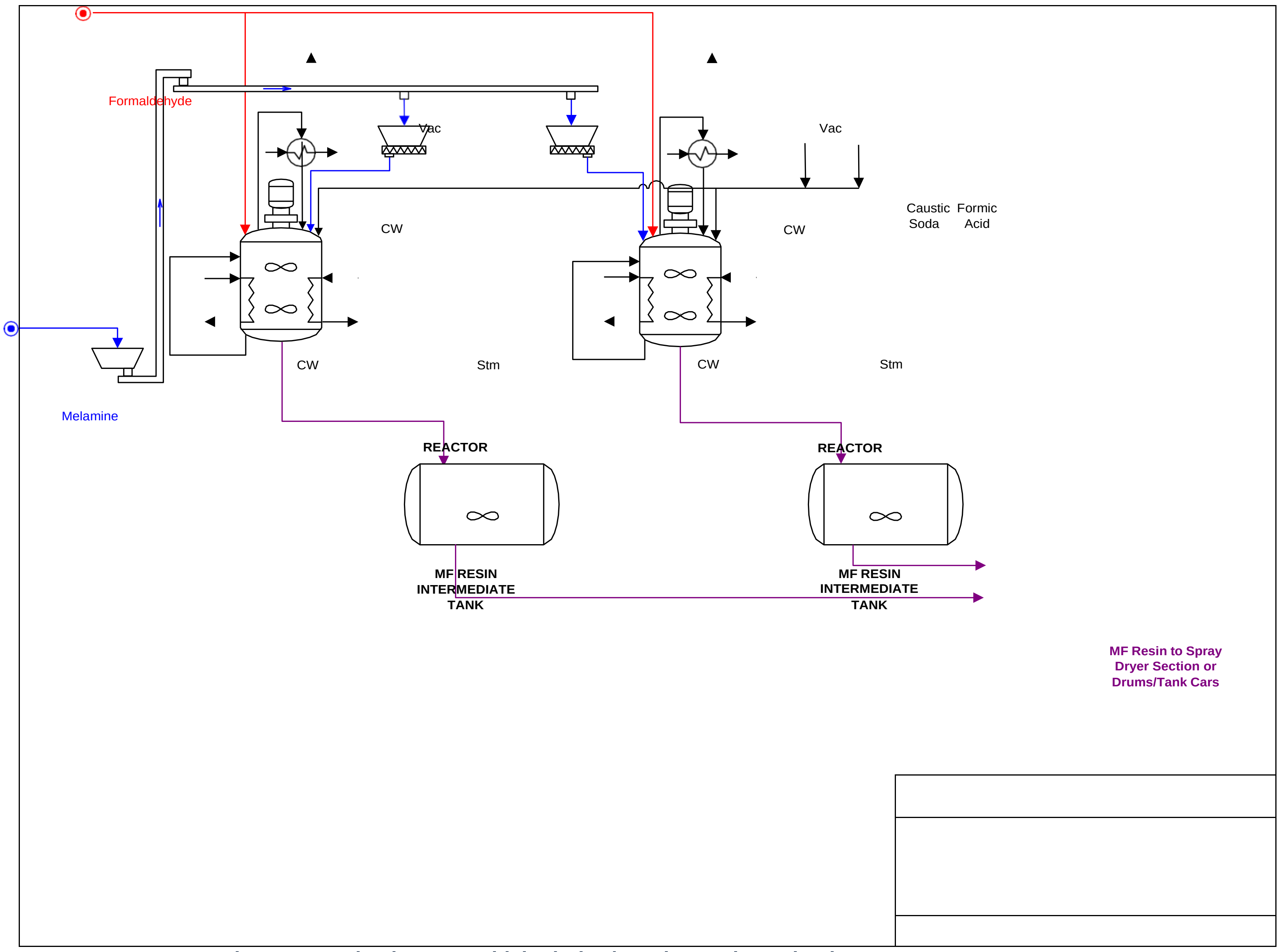


Figure 47- Melamine-Formaldehyde (MF) Resin Batch Production Process

3-11- PHENOL-FORMALDEHYDE (PF) RESINS

3-11-1- Introduction

This family of resins made from phenol and formaldehyde can be produced to meet a wide range of market requirements by varying the reaction conditions. The most important variables are:

- Molar ratio of phenol to formaldehyde
- Type and amount of catalyst
- Reaction time and temperature
- Water content of final resin

Phenol-formaldehyde (PF) resins are normally produced by a batch process in relatively small plants. Pollution control, requiring incineration or other treatment of phenolic wastes, and safety are important considerations.

Depending on the formaldehyde/phenol (F/P) ratio and the concentration and type of catalyst, the reactions result in two principal types of PF resins:

- Novolacs – These resins are produced in an acidic environment where there is excess phenol over formaldehyde (F<P). The F/P molar ratio is typically in the range of 0.5:1 to 0.8:1. Oxalic acid is usually employed as the catalyst, but other acids have been used. Novolacs are cured in a two- step process by the addition of a second component, such as hexamethylenetetramine (hexamine or hexa), and/or heat. Novolacs are thermoplastic-type compounds and are usually brittle solids that react with various cross-linking substances (e.g., hexamine) to give the resin its final properties. They are usually supplied as powders or flakes.
- Resols – These resins are produced in an alkaline solution where there is an excess of formaldehyde over phenol (F>P). The F/P molar ratio is typically in the range of 1.2:1 to 3.0:1. An alkaline (basic) catalyst is used. Resols, being thermoset-type compounds, are cured by heat with or without the use of a catalyst in a one-step process, to advance polymerization and cross-linking. Resols represent the bulk of PF resin production. They are generally prepared as aqueous solutions, but can also be supplied as organic solvent solutions or in powder form.

Phenol derivatives, substituted phenols such as cresol and resorcinol, can also be reacted with formaldehyde to produce PF resins, but these resins are not covered in this report.

3-11-2- Process Description

- ## Novolac Production

Novolac resins are produced with an excess of phenol to formaldehyde (molar ratio of F<P). The molar ratio affects the structure and density of the resin, the curing behavior, and residual monomer content. Oxalic acid is usually employed as the catalyst, but other acids have been used including sulfuric acid with raw materials of low reactivity and maleic acid for particularly high melting point resins. The catalyst and reaction conditions affect the molecular structure of the resin produced and its properties. Novolacs are cured in a two-step process by the addition of a second component, such as hexamethylenetetramine (hexa) and heat. Novolacs are thermoplastic-type compounds and are usually brittle solids that react with various cross-linking substances (e.g., hexa, formaldehyde) to give the resin its final properties. They are usually supplied as solid flake or pastille (granule) or dissolved in a solvent. Novolacs have a relatively long shelf life (about two years), so they can be shipped long distances.

The production process for novolac phenol-formaldehyde (PF) resins can be represented by two steps. The first step is a substitution/addition reaction of formaldehyde with phenol to form a hydrated benzylic carbonium ion at the *ortho-* or *para-* position (relative to the hydroxyl group). The second step is the condensation reaction between an intermediate product and a phenol molecule, forming methylene bridges between the two rings, with the release of water. Novolacs, unlike resols, do not have reactive functional groups, which is why they cannot self-cure. Production processes are typically designed for batches, with reactors as large as 60 m^3 for large volume applications, but much smaller for low volume applications. A typical batch cycle time is eight hours.

A simplified process flow sheet is shown in Figure 4.1. The process shown is a batch process carried out in stainless steel reactors that are equipped with an agitator to ensure good mixing. For heating and cooling, the reactor is jacketed and/or equipped with internal coils. The reactor is also equipped with a condenser that is used for reflux and distillation, and also with the option of applying vacuum. Depending on the plant capacity, multiple reactors can be used; two are shown in the flow sheet.

Formaldehyde solution and phenol are charged to the reactor by means of a pump from a storage tank. The formaldehyde is supplied either directly through a pipeline from an on-site formaldehyde plant or by tank car. Formalin (37 weight percent formaldehyde) has typically been used. However, modern plants use higher concentrations (up to about 55 weight percent) to save the energy required to heat and distill the extra water and to minimize wastewater. Molten (90 to 100 percent) phenol is used for the same reasons. However, this requires the storage tanks and feed systems

to be heated. Chemicals used as catalyst and/or for the adjustment of the pH of the batch are charged into the reactor from charging tanks.

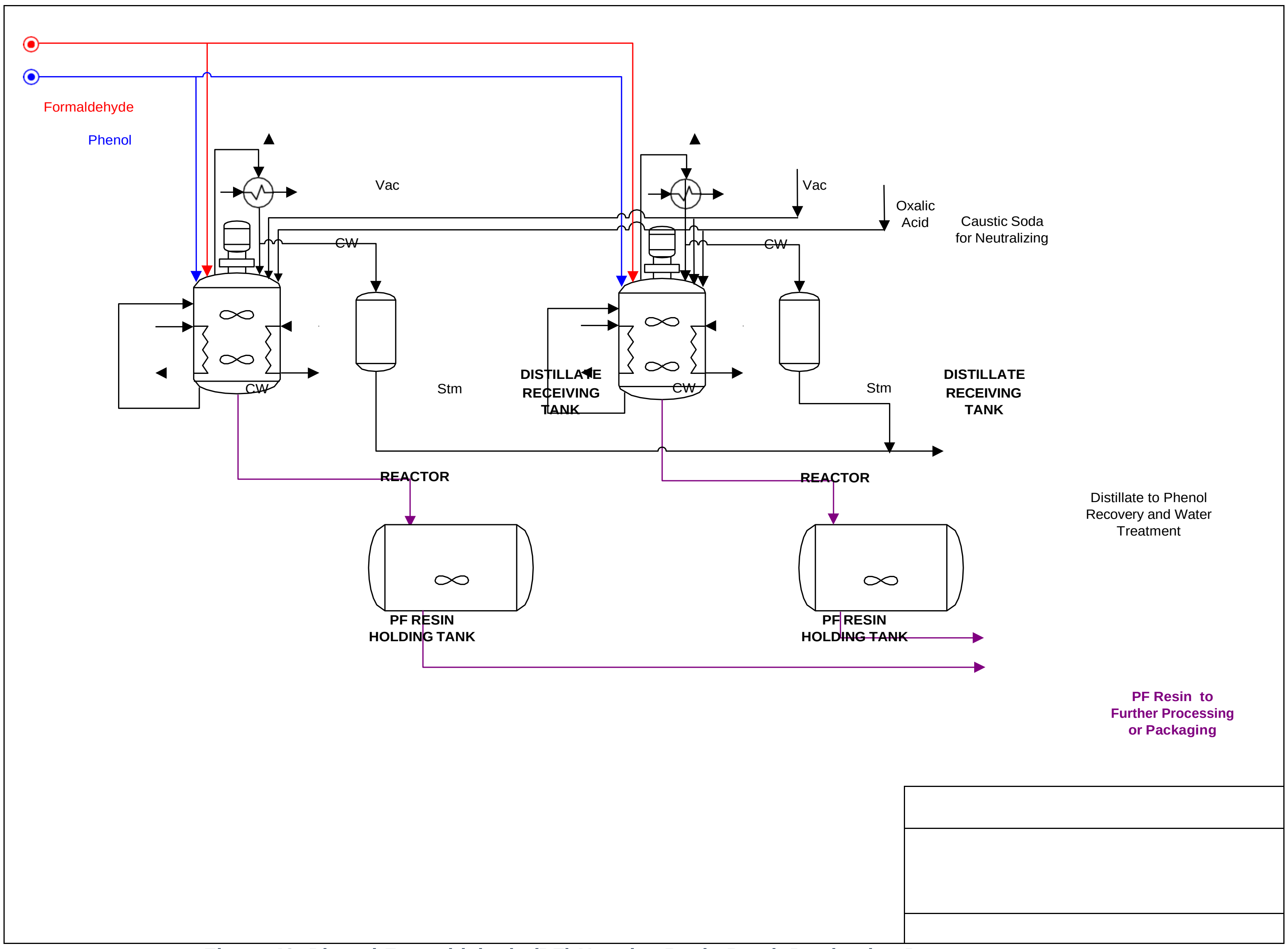


Figure 48- Phenol-Formaldehyde (PF) Novolac Resin Batch Production Process

4- Financial Report Summary

Assumptions for calculating Financial and Economic indicators	
Construction period	3 Years
Operation period	25 Years
Financing	Loan (Finance): 65% of CAPEX Equity: 35% of CAPEX Loan Re-imbursement period: 15 Years Interest rate: 2% Grace Period: 2.5 Years Discount rate: 5.5%
CAPEX distribution during construction years:	First year: 40% Second year: 50% Third year: 10%
Operation rate	First year: 70% Second year:80% Third to twentieth year: 100%
Discount Rate	5.5%
Tax Rate	20%

Table 12- CAPEX (1000 Dollars)

Item No	Cost Item	Formaldehyde	Urea-Formaldehyde	Melamine-Formaldehyde	Phenol-Formaldehyde	Syn gas/co	Acetic Acid	LDPE	Vinyl Acetate	Polyvinyl Alcohol	Methylamine	Polyacetal	Total
1	Inside Battery Limits	14,870	8,660	8,660	8,660	64,150	92,500	25,000	83,150	74,150	24,400	117,650	521,850
2	Land Purchase Cost	315	209	209	209	176	254	69	228	203	67	323	2,262
3	Land preparation and landscaping	633	420	420	420	353	510	138	458	409	134	648	4,542
4	Buildings: Industrial and non-industrial buildings, laboratory, workshop and firefighting equipment	2,778	1,052	1,052	1,052	886	1,277	345	1,148	1,024	337	1,624	12,574
5	Storage tanks for raw materials, products and water storage tanks	5,371	2,772	2,772	2,772	2,334	3,365	910	3,025	2,698	888	4,280	31,187
6	Cooling Towers	525	348	348	348	293	423	114	380	339	112	538	3,771
7	Steam units	716	475	475	475	400	577	156	519	462	152	734	5,142
8	Air and Nitrogen units		1,584	1,584	1,584	1,334	1,923	520	1,729	1,542	507	2,446	14,752
9	Primary effluent treatment units	501	333	333	333	280	404	109	363	324	107	514	3,599
10	Process water treatment units and boilers	358	238	238	238	200	288	78	259	231	76	367	2,571
11	Flare (Integrated Torch)	239	158	158	158	133	192	52	173	154	51	245	1,714
12	Road construction	43	29	29	29	24	35	9	31	28	9	44	308
13	Vehicles and Safety	143	95	95	95	80	115	31	104	92	30	147	1,028
14	Diesel Generator	358	238	238	238	200	288	78	259	231	76	367	2,571
Total		**26,850**	**16,610**	**16,610**	**16,610**	**70,844**	**102,152**	**27,609**	**91,826**	**81,887**	**26,946**	**129,926**	**607,870**

Table 13- Inside Battery Limits Expenditures (1000 Dollars)

Item No	Item	Formaldehyde	Urea-Formaldehyde	Melamine-Formaldehyde	Phenol-Formaldehyde	Syn gas/co	Acetic Acid	LDPE	Vinyl Acetate	Polyvinyl Alcohol	Methylamine	Polyacetal	Total
1	License	385	224	224	224	1,800	2,500	647	2,600	1,900	500	1,800	12,804
2	Basic engineering	516	301	301	301	3,300	3,800	868	3,600	2,400	750	2,200	18,335
3	Detailed engineering	678	395	395	395	4,000	4,500	1,140	4,200	4,800	1,000	3,000	24,502
4	Procurement and purchase engineering	8,653	5,039	5,039	5,039	36,000	51,000	14,547	48,000	42,000	14,500	73,000	302,817
5	Installation and supplies	3,734	2,174	2,174	2,174	16,000	24,000	6,277	16,500	19,000	6,000	32,000	130,034
6	Start-up and pre-start-up costs	111	65	65	65	600	700	186	650	600	250	750	4,041
7	Catalysts and chemicals	302	176	176	176	200	3,000	508	4,750	900	400	1,400	11,987
8	Spare parts for two years	347	202	202	202	1,500	2,000	583	1,900	1,700	600	2,900	12,135
9	Project supervision	75	44	44	44	350	550	126	500	450	150	250	2,583
10	Personnel training	70	41	41	41	400	450	118	450	400	250	350	2,610
Total		**14,870**	**8,660**	**8,660**	**8,660**	**64,150**	**92,500**	**25,000**	**83,150**	**74,150**	**24,400**	**117,650**	**521,850**

Table 14- OPEX (1000 Dollars)

Item	Formaldehyde	Urea-Formaldehyde	Melamine-Formaldehyde	Phenol-Formaldehyde	Syn gas / co	AA	LDPE	VAM	PVOH	MA	POM	Total
Variable	**23,242**	**15,314**	**47,141**	**52,087**	**6,949**	**26,926**	**46,934**	**74,389**	**12,902**	**11,121**	**40,900**	**357,905**
Raw material	15,600	8,690	40,315	45,418	404	21,255	37,196	58,888	0	5,246	10,920	243,931
Utility	7,183	5,522	5,522	5,522	5,071	4,253	8,523	14,812	12,634	4,633	19,662	93,339
Environmental Taxes	170	408	483	425	546	525	450	255	100	460	3,821	7,643
Research and Development	170	408	483	425	546	525	450	255	100	460	3,821	7,643
Sales & Marketing	119	286	338	298	382	368	315	179	70	322	2,675	5,350
FIXED	**853**	**2,343**	**2,343**	**2,343**	**3,999**	**5,804**	**1,541**	**5,097**	**4,574**	**1,530**	**7,646**	**38,071**
Maintenance	495	307	307	307	1,216	1,801	493	1,604	1,434	484	2,439	10,889
Wages and Salary	250	1,969	1,969	1,969	2,500	3,594	938	3,125	2,813	938	4,688	24,750
Plant Insurance	107	66	66	66	283	409	110	367	328	108	520	2,431
Total Operation Expenditures (OPEX)	**24,095**	**17,656**	**49,483**	**54,430**	**10,949**	**32,729**	**48,474**	**79,486**	**17,477**	**12,651**	**48,547**	**395,976**

Table 15- Utility Consumption Summary

Item No	Unit	Formaldehyde	Urea-Formaldehyde	Melamine-Formaldehyde	Phenol-Formaldehyde	Syn gas / co	AA	LDPE	VAM	PVOH	MA	POM	offsite	Total
1	Electricity (MW)	53,064	35,006	35,006	35,006	43,000	12,000	94,000	7,000	11,460	530	28,500	132,190	486,763
2	Rotating Cooling Water (Thousand cubic meters)	10,660	1,088	1,088	1,088	5,400	12,000	10,300	23,000	16,600	6,000	114,000	5,000	206,224
3	DM Water (Thousand cubic meters)	832	0	0	0	30	0	50	0	31	0	600	0	1,543
4	Steam (Thousand Tons)	40	61	61	61	4	52	-18	460	374	110	384	0	1,590
5	Natural gas fuel (Thousand cubic meters)	0	0	0	0	2,700	0	0	0	0	0	4,800	90,000	97,500
6	Instrument Air (Thousand cubic meters)	0	0	0	0	250	400	350	350	100	50	100	50	1,650
7	Unit Air (Thousand cubic meters)	0	0	0	0	150	300	200	250	50	50	50	150	1,200
8	Nitrogen (Thousand Cubic Meters)	0	401	401	401	200	500	350	300	750	150	4,600	150	8,204
9	Oxygen (Thousand Cubic Meters)	0	0	0	0	42,000	0	0	29,000	0	0	0	0	71,000

Table 16- CAPEX, OPEX And Revenues (1000 Dollars)

Unit	CAPEX	OPEX - Variable	OPEX - FIXED	Revenues
Formaldehyde*	26,850	23,242	853	34,000
Urea-Formaldehyde	16,610	15,314	2,343	81,600
Melamine-Formaldehyde	16,610	47,141	2,343	96,560
Phenol-Formaldehyde	16,610	52,087	2,343	85,000
Syn gas/co	70,844	6,949	3,999	0
Acetic Acid	102,152	26,926	5,804	109,220
LDPE	27,609	46,934	1,541	105,000
Vinyl Acetat	91,826	74,389	5,097	90,000
Polyvinyl Alcohol	81,887	12,902	4,574	51,000
Methylamine	26,946	11,121	1,530	19,900
Polyacetal	129,926	40,900	7,646	92,000

The expenses and revenues mentioned in the above table are related to the sale of all produced formaldehyde, if a part of the production is consumed by the downstream units, the expenses and revenues will be reduced.

4-1- Construction phasing

Table 17- CAPEX, OPEX And Revenues by Phase (1000 Dollars)

	Unit	CAPEX		OPEX - Variable		OPEX - FIXED		Revenues	
Phase 1	Formaldehyde	26,850	87,016	22,939	101,461	853	7,068	11,560	198,060
	Urea-Formaldehyde	16,610		15,314		2,343		81,600	
	Phenol-Formaldehyde	16,610		52,087		2,343		85,000	
	Methylamine	26,946		11,121		1,530		19,900	

	Unit	CAPEX		OPEX - Variable		OPEX - FIXED		Revenues	
Phase 2	Melamine-Formaldehyde	16,610	309,041	47,141	202,339	2,343	18,783	96,560	400,780
	Syn gas/co	70,844		6,949		3,999		0	
	Acetic Acid	102,152		26,926		5,804		109,220	
	LDPE	27,609		46,934		1,541		105,000	
	Vinyl Acetate	91,826		74,389		5,097		90,000	

	Unit	CAPEX		OPEX - Variable		OPEX - FIXED		Revenues	
Phase 3	Polyvinyl Alcohol	81,887	211,813	12,902	53,500	4,574	12,221	51,000	143,000
	Polyacetal	129,926		40,597		7,646		92,000	

Table 18- Equity Needed in Construction Period by Phase (1000 Dollars)

Phase 1	1	2	3
Equity	12,182	15,228	3,046
Loan	22,624	28,280	5,656
Total	**34,806**	**43,508**	**8,702**

Phase 2	1	2	3
Equity	43,266	54,082	10,816
Loan	80,351	100,438	20,088
Total	**123,616**	**154,520**	**30,904**

Phase 3	1	2	3
Equity	29,654	37,067	7,413
Loan	55,071	68,839	13,768
Total	**84,725**	**105,907**	**21,181**

Table 19- Phase 1 Cash Flow (1000 Dollars)

				Cnstruction Period			Operation Period											
	Description			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Phase 1	Revenues						138,642	158,448	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060
	Costs	CAPEX	Equity	12,182	15,228	3,046												
			loan	22,624	28,280	5,656												
		Operation costs		0	0	0	78,090	88,236	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529
	Gross profit			-34,806	-43,508	-8,702	60,552	70,212	89,531	89,531	89,531	89,531	89,531	89,531	89,531	89,531	89,531	89,531
	Amortization			0	0	0	39,157	34,806	30,456	26,105	21,754	17,403	13,052	8,702	4,351	0	0	0
	Financing costs			0	0	0	0	0	2,413	4,827	4,827	4,827	4,827	4,827	4,827	4,827	4,827	4,827
	Net profit			-34,806	-43,508	-8,702	21,395	35,405	56,663	58,600	62,951	67,302	71,652	76,003	80,354	84,705	84,705	84,705
	Tax			0	0	0	4,279	7,081	11,333	11,720	12,590	13,460	14,330	15,201	16,071	16,941	16,941	16,941
	Net cash flow			-34,806	-43,508	-8,702	17,116	28,324	45,330	46,880	50,361	53,841	57,322	60,803	64,283	67,764	67,764	67,764
	Acumulative cash flow			-34,806	-78,314	-87,016	-69,900	-41,576	3,754	50,634	100,994	154,836	212,158	272,960	337,244	405,008	472,771	540,535

				Operation Period									
	Description			**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Phase 1	Revenues			198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060
	Costs	CAPEX	Equity										
			loan										
		Operation costs		108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529
	Gross profit			89,531	89,531	89,531	89,531	89,531	89,531	89,531	89,531	89,531	89,531
	Amortization			0	0	0	0	0	0	0	0	0	0
	Financing costs			4,827	4,827	4,827	4,827	4,827	2,413	0	4,827	4,827	4,827
	Net profit			84,705	84,705	84,705	84,705	84,705	87,118	89,531	84,705	84,705	84,705
	Tax			16,941	16,941	16,941	16,941	16,941	17,424	17,906	16,941	16,941	16,941
	Net cash flow			67,764	67,764	67,764	67,764	67,764	69,695	71,625	67,764	67,764	67,764
	Acumulative cash flow			608,299	676,063	743,827	811,591	879,355	949,049	1,020,675	1,088,439	1,156,202	1,223,966

In the ninth year, more Total Equity needed to Construct the phase2 is available, and the construction of the phase2 will begin in the tenth year.

Table 20- Phase 2 Cash Flow (1000 Dollars)

				Cnstruction Period			Operation Period											
	Description			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Phase 2	Revenues			0	0	0	280,546	320,624	400,780	400,780	400,780	400,780	400,780	400,780	400,780	400,780	400,780	400,780
	Costs	CAPEX	Equity	43,266	54,082	10,816												
			loan	80,351	100,438	20,088												
		Operation costs		0	0	0	160,420	180,654	221,121	221,121	221,121	221,121	221,121	221,121	221,121	221,121	221,121	221,121
	Gross profit			-43,266	-54,082	-10,816	120,126	139,970	179,659	179,659	179,659	179,659	179,659	179,659	179,659	179,659	179,659	179,659
	Amortization			0	0	0	139,068	123,616	108,164	92,712	77,260	61,808	46,356	30,904	15,452	0	0	0
	Financing costs								8,571	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142
	Net profit			-43,266	-54,082	-10,816	-18,942	16,354	62,924	69,805	85,257	100,709	116,161	131,613	147,065	162,517	162,517	162,517
	Tax			0	0	0	0	3,271	12,585	13,961	17,051	20,142	23,232	26,323	29,413	32,503	32,503	32,503
	Net cash flow			-123,616	-154,520	-30,904	-18,942	13,083	58,910	72,986	85,347	97,709	110,070	122,432	134,794	147,155	147,155	147,155
	Acumulative cash flow			-123,616	-278,137	-309,041	-327,983	-314,899	-255,989	-183,004	-97,657	52	110,123	232,555	367,348	514,504	661,659	808,814

				Operation Period														
	Description			**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**					
Phase 2	Revenues			400,780	400,780	400,780	400,780	400,780	400,780	400,780	400,780	400,780	400,780					
	Costs	CAPEX	Equity															
			loan															
		Operation costs		221,121	221,121	221,121	221,121	221,121	221,121	221,121	221,121	221,121	221,121					
	Gross profit			179,659	179,659	179,659	179,659	179,659	179,659	179,659	179,659	179,659	179,659					
	Amortization			0	0	0	0	0	0	0	0	0	0					
	Financing costs			17,142	17,142	17,142	17,142	17,142	8,571	0	0	0	0					
	Net profit			162,517	162,517	162,517	162,517	162,517	171,088	179,659	179,659	179,659	179,659					
	Tax			32,503	32,503	32,503	32,503	32,503	34,218	35,932	35,932	35,932	35,932					
	Net cash flow			147,155	147,155	147,155	147,155	147,155	145,441	143,727	143,727	143,727	143,727					
	Accumulative cash flow			955,970	1,103,125	1,250,280	1,397,436	1,544,591	1,690,032	1,833,759	1,977,486	2,121,213	2,264,940					

In the 14th year, the phase2 will be operated, and at the end of the same year, the equity needed to Construct the phase3 will be provided from the plants revenues. In the 15th year, the construction of the phase3 will begin.

Table 21- Phase 3 Cash Flow (1000 Dollars)

Phase 3				Cnstruction Period			Operation Period											
	Description			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Revenues			0	0	0	100,100	114,400	143,000	143,000	143,000	143,000	143,000	143,000	143,000	143,000	143,000	143,000
	Costs	CAPEX	Equity	29,654	37,067	7,413												
			loan	55,071	68,839	13,768												
		Operation costs		0	0	0	0	49,670	55,020	65,720	65,720	65,720	65,720	65,720	65,720	65,720	65,720	65,720
	Gross profit			-29,654	-37,067	-7,413	50,430	59,380	77,280	77,280	77,280	77,280	77,280	77,280	77,280	77,280	77,280	77,280
	Amortization			0	0	0	95,316	84,725	74,135	63,544	52,953	42,363	31,772	21,181	10,591	0	0	0
	Financing costs			0	0	0	0	0	5,874	11,749	11,749	11,749	11,749	11,749	11,749	11,749	11,749	11,749
	Net profit			-29,654	-37,067	-7,413	-44,886	-25,346	-2,729	1,987	12,578	23,168	33,759	44,350	54,940	65,531	65,531	65,531
	Tax			0	0	0	0	0	0	397	2,516	4,634	6,752	8,870	10,988	13,106	13,106	13,106
	Net cash flow			-84,725	-105,907	-21,181	-44,886	-25,346	3,145	13,338	21,811	30,283	38,756	47,228	55,701	64,174	64,174	64,174
	Acumulative cash flow			-84,725	-190,632	-211,813	-256,700	-282,046	-278,901	-265,562	-243,751	-213,468	-174,712	-127,484	-71,783	-7,609	56,564	120,738

Phase 3				Operation Period														
	Description			16	17	18	19	20	21	22	23	24	25					
	Revenues			143,000	143,000	143,000	143,000	143,000	143,000	143,000	143,000	143,000	143,000					
	Costs	CAPEX	Equity															
			loan															
		Operation costs		65,720	65,720	65,720	65,720	65,720	65,720	65,720	65,720	65,720	65,720					
	Gross profit			77,280	77,280	77,280	77,280	77,280	77,280	77,280	77,280	77,280	77,280					
	Amortization			0	0	0	0	0	0	0	0	0	0					
	Financing costs			11,749	11,749	11,749	11,749	11,749	11,749	5,874	0	0	0					
	Net profit			65,531	65,531	65,531	65,531	65,531	65,531	71,405	77,280	77,280	77,280					
	Tax			13,106	13,106	13,106	13,106	13,106	13,106	14,281	15,456	15,456	15,456					
	Net cash flow			64,174	64,174	64,174	64,174	64,174	64,174	62,999	61,824	61,824	61,824					
	Acumulative cash flow			184,911	249,085	313,258	377,432	441,605	505,779	568,778	630,601	692,425	754,249					

Table 22- Plant Cash Flow (1000 Dollars)

				Cnstruction Period			Operation Period											
	Description			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Plant	Revenues			0	0	0	138,642	158,448	198,060	198,060	198,060	198,060	198,060	198,060	198,060	478,606	518,684	598,840
	Costs	CAPEX	Equity	12,182	15,228	3,046	0	0	0	0	0	0	43,266	54,082	10,816	0	0	29,654
			loan	22,624	28,280	5,656	0	0	0	0	0	0	80,351	100,438	20,088	0	0	55,071
		Operation costs			0	0	78,090	88,236	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529	268,948	289,182
	Gross profit			-34,806	-43,508	-8,702	60,552	70,212	89,531	89,531	89,531	89,531	-34,085	-64,989	58,627	209,658	229,502	184,465
	Amortization			0	0	0	39,157	34,806	30,456	26,105	21,754	17,403	13,052	8,702	4,351	139,068	123,616	108,164
	Financing costs			0	0	0	0	0	2,413	4,827	4,827	4,827	4,827	4,827	4,827	4,827	4,827	13,397
	Net profit			-34,806	-43,508	-8,702	21,395	35,405	56,663	58,600	62,951	67,302	-51,964	-78,517	49,450	65,763	101,059	62,903
	Tax			0	0	0	4,279	7,081	11,333	11,720	12,590	13,460	0	0	9,890	13,153	20,212	12,581
	Net cash flow			-34,806	-43,508	-8,702	17,116	28,324	45,330	46,880	50,361	53,841	-51,964	-78,517	39,560	52,610	80,847	50,323
	Acumulative cash flow			-34,806	-78,314	-87,016	-69,900	-41,576	3,754	50,634	100,994	154,836	102,872	24,355	63,915	116,525	197,373	247,695

				Operation Period									
	Description			**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Plant	Revenues			598,840	598,840	698,940	713,240	741,840	741,840	741,840	741,840	741,840	741,840
	Costs	CAPEX	Equity	37,067	7,413	0	0	0	0	0	0	0	0
			loan	68,839	13,768	0	0	0	0	0	0	0	0
		Operation costs		329,650	329,650	329,650	379,320	384,670	395,370	395,370	395,370	395,370	395,370
	Gross profit			163,283	248,009	319,620	328,570	346,470	346,470	346,470	346,470	346,470	346,470
	Amortization			92,712	77,260	157,124	131,081	105,039	78,996	52,953	42,363	31,772	21,181
	Financing costs			21,968	21,968	21,968	21,968	27,843	31,304	28,891	33,717	33,717	33,717
	Net profit			48,603	148,780	140,527	175,520	213,588	236,170	264,626	270,390	280,981	291,571
	Tax			9,721	29,756	28,105	35,104	42,718	47,234	52,925	54,078	56,196	58,314
	Net cash flow			38,882	119,024	112,422	140,416	170,871	188,936	211,701	216,312	224,785	233,257
	Acumulative cash flow			286,577	405,602	518,024	658,440	829,310	1,018,246	1,229,947	1,446,259	1,671,043	1,904,300

Table 23- CAPEX, OPEX and Revenues by Phase (1000 Dollars)

		Phas1 Construction period									Phas2 Construction period					Phas3 Construction period		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Phase 1	CAPEX	34,806	43,508	8,702	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OPEX	0	0	0	78,090	88,236	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529
	Revenues	0	0	0	138,642	158,448	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060
Phase 2	CAPEX	0	0	0	0	0	0	0	0	0	123,616	154,520	30,904	0	0	0	0	0
	OPEX	0	0	0	0	0	0	0	0	0	0	0	0	160,420	180,654	221,121	221,121	221,121
	Revenues	0	0	0	0	0	0	0	0	0	0	0	0	280,546	320,624	400,780	400,780	400,780
Phase 3	CAPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84,725	105,907	21,181
	OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Revenues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		18	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Phase 1	CAPEX	0	0	0	0	0	0	0	0
	OPEX	108,529	108,529	108,529	108,529	108,529	108,529	108,529	108,529
	Revenues	198,060	198,060	198,060	198,060	198,060	198,060	198,060	198,060
Phase 2	CAPEX	0	0	0	0	0	0	0	0
	OPEX	221,121	221,121	221,121	221,121	221,121	221,121	221,121	221,121
	Revenues	400,780	400,780	400,780	400,780	400,780	400,780	400,780	400,780
Phase 3	CAPEX	0	0	0	0	0	0	0	0
	OPEX	49,670	55,020	65,720	65,720	65,720	65,720	65,720	65,720
	Revenues	100,100	114,400	143,000	143,000	143,000	143,000	143,000	143,000

Table 24- Financial Indicators

Phase 1		
Economic indicators	**Value**	**Unit**
Net present value (NPV)	515,049	1000 Dollars
Internal Rate of Return (IRR)	31.60%	Percent
Payback period (PBP)	5	Year

Phase 2		
Economic indicators	**Value**	**Unit**
Net present value (NPV)	825,745	1000 Dollars
Internal Rate of Return (IRR)	18.42%	Percent
Payback period (PBP)	8	Year

Phase 3		
Economic indicators	**Value**	**Unit**
Net present value (NPV)	178,860	1000 Dollars
Internal Rate of Return (IRR)	9.94%	Percent
Payback period (PBP)	13	Year

Plant		
Economic indicators	**Value**	**Unit**
Net present value (NPV)	926,878	1000 Dollars
Internal Rate of Return (IRR)	27.40%	Percent
Payback period (PBP)	5	Year

Table 25- Sensitivity Analysis (Plant)

Percentage Change	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%
Revenue	8.39%	13.47%	18.40%	23.05%	**27.40%**	31.46%	35.22%	38.73%	42.01%
Utilty	29.32%	28.85%	28.37%	27.89%	**27.40%**	26.91%	26.42%	25.92%	25.42%
Row Material	33.51%	32.05%	30.54%	28.99%	**27.40%**	25.77%	24.10%	22.40%	20.68%
CAPEX	33.28%	31.65%	30.13%	28.72%	**27.40%**	26.17%	25.01%	23.92%	22.88%

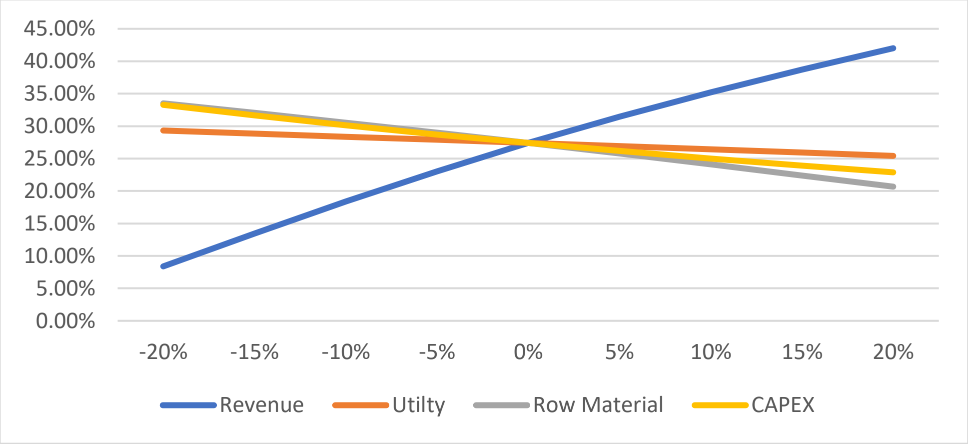



Figure 49- Sensitivity Analysis (Plant)